High Efficiency Fossil Power Plant (HEFPP)

Conceptualization Program

Final Report

Start Date: May 28, 1998
End Date: October 31, 1999

Principal Author: J.L. Justice

March 25, 1999

Contract No. DE-AC26-98FT40356--02

Submitted by:
M-C Power Corporation
8040 S. Madison Street
Burr Ridge, Illinois 60521-5808

Disclaimer

Abstract

This study confirms the feasibility of a natural gas fueled, 20 MW M-C Power integrated pressurized molten carbonate fuel cell combined in a topping cycle with a gas turbine generator plant. The high efficiency fossil power plant (HEFPP) concept has a 70 percent efficiency on a LHV basis. The study confirms the HEFPP has a cost advantage on a cost of electricity basis over the gas turbine based combined cycle plants in the 20 MW size range. The study also identifies the areas of further development required for the fuel cell, gas turbine generator, cathode blower, inverter, and power module vessel. The HEFPP concept offers an environmentally friendly power plant with minuscule emission levels when compared with the combined cycle power plant.

Table of Contents

	Page
Disclaimer	ii
Abstract	iii
Table of Contents	iv
List of Graphic Materials	v
1. Executive Summary	1-1
2. Introduction	2-1
3. Results and Discussion	3-A-1
A. Concept Verification	3-A-1
1. Design and Development Issues	3-A-1
a. Fuel Cell Stacks	3-A-1
b. Gas Turbine Generator	3-A-5
c. Balance of Plant	3-A-9
2. Confirmation of Design Parameters	3-A-13
a. Fuel Cell	3-A-13
b. Gas Turbine Generator	3-A-15
c. Balance of Plant	3-A-20
3. Optimum Operating Pressure Study	3-A-27
4. Optimum Number of Spare Trains for Each Major Process Area	3-A-33
B. System Definition	3-B-1
1. Process Description	3-B-1
2. Plant Performance Summary	3-B-7
a. Fuel Cell Stacks	3-B-7
b. Turbine Generator	3-B-8
c. Overall Plant	3-B-9
3. Process Flow Diagram	3-B-14
4. Control Concept	3-B-117
a. Fuel Cell	3-B-117
b. Turbine Generator	3-B-119
c. Overall Plant	3-B-122
5. List of Major Equipment	3-B-123
C. Economic Projections	3-C-1
1. Description of Estimate	3-C-1
2. Sources of Cost Data	3-C-2
3. Estimate of Capital and Operating Costs	3-C-3
4. Economic Analysis Results	3-C-11
5. Comparison of Fuel Cell Power Plant with Competing Technology	3-C-12
4. Conclusion	4-1

List of Graphics

	Page

Figures

1. Gas Turbine Cycle Efficiency – relative to maximum cycle efficiency 3-A-29

Drawings

1. B-001 3-B-15
2. B-002 3-B-21

Tables

1. Major Subsystem Design Parameters and Operating Conditions Site Elevation – Sea Level 3-A-23
2. Performance Summary Site Elevation – Sea Level SOR 3-A-24
3. Performance Summary Site Elevation – 5,000' 3-A-25
4. Performance Summary Site Elevation – Sea Level EOR 3-A-26
5. Performance Summary 3-A-32
6. Design Specification 3-B-5
7. Major Subsystem Design Parameters and Operating Conditions Site Elevation – Sea Level 3-B-10
8. Performance Summary Site Elevation – Sea Level SOR 3-B-11
9. Performance Summary Site Elevation – 5,000' 3-B-12
10. Performance Summary Site Elevation – Sea Level EOR 3-B-13
11. Material Balance – Full Load, SOR – Sea Level 15°C/-29°C Ambient Air 3-B-16
12. Material Balance – Full Load, SOR – 5,000' Elev./15°C/-29°C Ambient Air 3-B-18
13. Material Balance – Full Load EOR – Sea Level 15°C/49°C (0% Rel. Humidity) Ambinet Air 3-B-20
14. Material Balance – Full Load SOR – Sea Level 15°C/-29°C Ambient Air 3-B-22
15. Material Balance – Full Load SOR - -5,000 Elev./15°C/-29°C Ambient Air 3-B-24
16. Material Balance – Full Load EOR – Sea Level 15°C/49°C (0% Rel. Humidity) Ambient Air 3-B-26
17. Stream Summary Information Full-Load, SOR - Sea Level/15°C Ambient Air 3-B-27
18. Stream Summary Information Full-Load, SOR – Sea Level/-20°C Ambient Air 3-B-36
19. Stream Summary Information Full-Load, SOR – Sea Level/49°C (0% Rel. Humidity) Ambient Air 3-B-45
20. Stream Summary Information Full-Load, SOR – Sea Level/49°C (100% Rel. Humidity) Ambient Air 3-B-54
21. Stream Summary Information Full-Load, SOR –5,000' Elev./15°C Ambient Air 3-B-63
22. Stream Summary Information Full-Load, SOR –5,000' Elev./-20°C Ambient Air 3-B-72

Tables cont.

23. Stream Summary Information Full-Load, SOR –5,000' Elev./49°C (0% Rel. Humidity) Ambient Air 3-B-81
24. Stream Summary Information Full Load, SOR –5,000' Elev./49°C (100% Rel. Humidity) Ambient Air 3-B-90
25. Stream Summary Information Full-Load, EOR – Sea Level/15°C Ambient Air 3-B-99
26. Steam Summary Information Full-Load EOR – Sea Level/49°C (0% Rel. Humidity) Ambient Air 3-B-108
27. HEFPP Plant Organization Chart 3-C-6
28. HEFPP Major Equipment Cost List 3-C-7
29. Electric Power Generation Cost 3-C-8
30. Annual Operating Costs 3-C-9
31. COE-$/kW-h, NPV Calculation 20 MW MCFC Based HEFPP Facility 3-C-10
32. Combined Cycle Gas Turbine Electric Power Generation Cost 3-C-16
33. Combined Cycle Gas Turbine Annual Operating Costs 3-C-17
34. COE-$/kW h, NPV Calculation 22 MW CC- GT Plan 3-C-18

1. EXECUTIVE SUMMARY

This study shows that Pressurized Molten Carbonate Fuel Cell technology can be combined with gas turbine technology to produce a high efficiency power plant with 70 percent low heating value efficiency when utilizing natural gas as the fuel in the 20 MW plant size. The study has also proven that the high efficiency fossil power plant (HEFPP) concept produces a lower cost of electricity upon comparison with a similar size combined cycle plant. In the specific study case, the HEFPP concept cost to produce electricity was 6.3 cents per kWh as compared to the 7.1 cents per kWh for the gas turbine combined cycle case. The HEFPP concept also produces a much more environmentally friendly power plant with very low emissions of NOx , CO_2, and SOx, when compared to the gas turbine combined cycle case.

This study acknowledges that investments of capital and time in the HEFPP components must be made to drive the component costs down and to eliminate or improve specific problem areas. Specific components requiring further investment and development time include fuel cell stacks, gas turbine generator, recycle blower, power module vessel, and inverter. It should be noted that significant work to validate the process concept at smaller scale has already been completed or is in progress based on DOE funding for M-C Power's Process Design and Improvement Project under contract DE-FC21-95MC30133 and the ongoing MCFC power plant testing at Miramar.

2. INTRODUCTION

M-C Power Corporation was the prime contractor for the High Efficiency Fossil Power Plant concept study with Bechtel National, Inc., Rolls-Royce Allison, and Institute of Gas Technology (IGT) as the subcontractors.

The High Efficiency Fossil Power Plant (HEFPP) proposed concept consists of several integrated molten carbonate fuel cells (MCFC) serving as a topping cycle to a variable speed gas turbine driving an air compressor and electric alternator. The power plant will produce approximately 20 MW of power when natural gas is used as the fuel source. The gas turbine compressor section provides compressed air at a pressure ratio of 6 to the MCFC. The MCFC provides hot exhaust gas for expansion in the gas turbine, which drives both the compressor section and the alternator. DC power from the fuel cells is run through inverters where the voltage is converted. The AC power is elevated to 4160VAC. The power from the gas turbine alternator is directed through a power conditioner whereby the frequency is corrected to 60 Hz and the voltage is changed to 4160VAC. It should be noted that the design concept for the HEFPP is based on M-C Power's 450 kW MCFC power plant.

The main goal of the HEFPP study is to have a minimum overall plant efficiency of 70 percent excluding the potential for excess steam generation for cogeneration purposes from the high temperature gas turbine exhaust. Other goals are to achieve low environmental emissions and have high reliability with no major technical barriers for commercialization by the year 2010. An economic goal is to have the HEFPP plant to achieve a reduction by 10 to 20% for the cost of electricity price below a conventional gas turbine combined cycle plant.

This study identifies the design and development issues associated with the proposed HEFPP, confirms the design parameters of the various plant components, provides the process description and plant performance summary, makes economic projections for the plant capital and operating costs, and establishes the plant life cycle costs and cost of electricity. The HEFPP concept has been compared to a similar size gas fired gas turbine based combined cycle power plant with similar environmental emissions to assess the economic viability of the project.

3. RESULTS AND DISCUSSTION

3.A Concept Verification

This report section addresses the design and development issues and design parameters for the HEFPP concept by looking at the fuel cell, gas turbine generator and the balance of plant. Optimization of the cycle operating pressure and the number of spare trains are also addressed in this section.

3.A.1. Design and Development Issues

3.A.1.a <u>Fuel Cell Stack</u>

The molten carbonate fuel cell (MCFC) stacks in the High Efficiency Fossil Power Plant (HEFPP) study are the next generation of the full-area commercial-size MCFC stacks. Verification of the new generation has begun at M-C Power's pressurized test facility with a 75 kW demonstration stack at Miramar Marine Corps Air Station near San Diego. The development plan for cell package engineering to meet the required commercialization cost, power density and life goals for the year 2000 to 2006 time frame is in place as part of the present DOE funded Process Design Improvement (PDI) program (DOE Contract No. DE-FC21-95MC30133). The following design and development issues are being considered for successful implementation of the MCFC for the high-efficiency power plants:

Endurance (stack life) under HEFPP operating conditions.

The projected stack life under HEFPP operating conditions is 40,000 hours. There are no physical laws or technical data that states that this goal is beyond reach and cannot be achieved by 2008-2010.

The issues limiting stack life include:

(a) NiO cathode dissolution in the electrolyte and electrical shorting by Ni deposition in the matrix,
(b) electrolyte loss by corrosion of the separator plate and metal current collectors, and electrolyte loss by evaporation,
(c) matrix ability to retain electrolyte due to change of matrix pore structure and phase composition,
(d) matrix crack-resistance,
(e) separator plate corrosion,
(f) wet-seal corrosion protection and efficiency of sealing.

NiO cathode dissolution in electrolyte and electrical shorting by Ni deposition in the matrix

The issue of cathode dissolution and Ni-shorting through the matrix is being addressed by using additives, such as CaO or $CaCO_3$, to the Li-Na carbonate electrolyte. A stabilized cathode also reduces the potential for shorting. The use of LiNa significantly reduces NiO cathode dissolution. The Dutch experimental data suggests that MCFC stacks can operate between 30,000-50,000 hours before the shorting occurs. An Institute of Gas Technology (IGT) bench-scale fuel cell had operated for >17,000 hours with no shorting. Additional development work and testing are planned to confirm the stack life can be increased to the 40,000-hour goal.

Electrolyte losses

To abate electrolyte loss by corrosion of the separator plate and current collectors, material selection for the cell cathode side is being analyzed and design modifications are being considered. The 310S has better corrosion resistance than 316L; however, the analysis has shown that 310S stainless steel consumes more electrolyte for corrosion than 316L. The purpose of the design modifications is to reduce the metal surface area exposed to electrolyte and, by doing that, to reduce electrolyte losses by corrosion. Considerable reduction of the electrolyte loss by evaporation has already been achieved by changing from Li-K to Li-Na electrolytes per M-C Power and IGT bench scale testing. The 310 S material will be tested at Miramar in a 75 kW stack as part of the Process Design Improvement Project.

Matrix pore structure and phase composition change

The ability of the matrix to retain electrolyte depends on $LiAlO_2$ phase stability and particle growth. It was found that α-$LiAlO_2$ is more stable than γ-$LiAlO_2$ at the normal operating temperature of ~ 650°C. However, recent IHI experience has proven that γ-$LiAlO_2$ can be stable if very high purity constituents and very small uniform particles are used, which increases stack life to 40,000 hours. For its previous stacks, M-C Power has used γ-$LiAlO_2$ matrices; but both approaches are being evaluated for future matrix material.

Matrix crack-resistance

The matrices developed by M-C Power confirmed their ability to withstand multiple thermal cycles. A number of bench-scale cell tests, which have been performed at IGT, showed that cell performance, sealing, as well as matrix integrity were not compromised after 6-8 thermal cycles. Full area fuel cell thermal cycling tests are planned at Miramar as part of the PDI project.

Separator plate corrosion

Stainless steels 316L and 310S are the current choices for MCFC separator plate material. The nickel-clad layer is being used for the anode side because Ni is thermodynamically stable in the anode gas environment. With the Ni-coating protection, the anode side did not show any signs of corrosion attack after several thousand hours of operation. Based on published data [CFC Technology, 1993, V.93-3, p.158], the 0.002" thick Ni-layer may be sufficient for 40,000-hour operation. Economical considerations require elimination of the Ni-clad layer. M-C Power has been conducting studies of homogeneous materials that could be technically and economically suitable for the separator plate. This effort is ongoing.

Wet-seal corrosion protection

The wet-seal area simultaneously experiences reducing and oxidizing environments and requires a special corrosion protection. Aluminization of the stainless steel surface has been generally used for this purpose. M-C Power's plates have been aluminized by Al-spray with following heat-treatment to provide an inter-metallic corrosion-resistant coating. Based on projections of the experimental data [CFC Technology, 1993, Vol.93-3, p.160], the aluminized coating is sufficient for 40,000-hour operation provided that a consistent quality of coating is maintained. Further development of wet-seal aluminization is planned to improve the quality and to reduce the cost of the process.

Maximum hardware temperature

Another issue related to stack life is the maximum hardware temperature that is determined by the stack flow geometry. The lower the maximum hardware temperature, the longer stack life. For cross-flow stacks the maximum local hardware temperature is high (> 700°C), especially at a high current density. This issue is being addressed through plate and stack hardware design.

Stack Life Verification Testing

The required 40,000-hour stack life has to be verified via a comprehensive development and testing program that will encompass further improvement and cost reduction of individual components, cell packages, and small stacks operating under power plant conditions – gas compositions, flows, temperatures, pressures. A part of this program will include testing of full area stacks, 1000 cm2 and 100 cm2 stacks at increasing current densities, fuel utilizations and operating pressures.

Stack Design Issues

The main MCFC stack design improvement issues include the following:

1. Development of a cost-effective, reliable and "simple" clamping system for the commercial design. The prototype clamping system, which will be implemented on M-C Power's 450 kW demonstration project, will eliminate use of the bellows and the associated bellows control system by use of springs.
2. Development of a cost-effective and "thin" cathode endplate that will improve thermal cyclability and sealing at the top by conforming to the stack. M-C Power is presently working on this problem as part of the PDI program.
3. Development of a commercial-design plenum to provide proper flow conditions at minimum cost and space. The initial designs will be tested in the 450 kW demonstration project. The plenum will require redesign at the 600 kPa operating pressure as the specific volume of gas is significantly different from the 300 kPa used on the 450 kW power plant.
4. Development of a commercial-design power-bus that satisfies electrical and mechanical requirements. The prototype will be tested in the 450 kW demonstration projected under the Process Design & Improvement Contract. The power bus will

require rework in the HEFPP project as four stacks will be combined and equipment location and geometries will be different in the 600 kPa power module vessel.

5. Electrical connection of several stacks in series which will raise the total voltage going to the inverter, reduces the inverter cost, improves inverter electrical efficiency, and improves the overall plant efficiency.

Confirmation of predicted performance and endurance at the 600 kPa pressure level will require both bench scale and full cell area testing. With the increase in pressure over the 300 kPa PDI project, the stack pressure drops (plenum arrangement internal manifolding, and plate spacing) will require review and possible redesign to reach the desired pressure drops.

3.A.1.b <u>Gas Turbine Generator</u>

The 3.8 MW Rolls-Royce Allison gas turbine generator must be designed and developed prior to use in the HEFPP project. Specific issues are addressed individually below:

Direct Drive Alternators (DDA)

The advantage of the direct drive alternator is that it eliminates the need for a gearbox between the turbo-machinery and the generator that it drives. This, in turn, opens the way to totally oil-free system providing appropriate bearings are used. The best bearing system is considered to be an Active Magnetic Bearing (AMB) configuration.

The DDA is to be run asynchronously such that there is an option to adjust the turbogenerator speed to suit the selected plant power level. It is anticipated that the plant turndown efficiency will be enhanced if the turbogenerator flow can be decreased at low power level (to prevent overcooling of the stack and to diminish the exhaust energy drain). Although this could be achieved to a degree by using variable vanes at a fixed turbine generator speed, asynchronous running offers a physically simpler and more thermodynamically efficient approach.

DDAs have been developed up to about 75 kW for use with microturbines and individual units have been demonstrated up to approximately 300 kW but not up to the 3.8 MW level. High speed electric motors, which may be regarded as close mirror images of DDAs have been produced at high power [Drives and Controls magazine July/August 1998 which reports an 8 MW motor with a design speed of 10,000 RPM]. The 3.8 MW, 11,000 to 15,000 RPM DDA required for this application must be designed in a manner which is compatible with the overall plant control scheme and, to this extent a new design task is created. Although the solution will be new in detail, it will represent a focusing of available technologies rather than a step into the unknown.

The power conditioning system is anticipated to take high frequency AC from the DDA, rectify it, and then convert it to 60 Hz in a converter dedicated to the turbogenerator. The mechanical integration of the compressor, turbine and DDA will be much facilitated by the use of AMBs, because they permit tuning of equivalent support stiffness to tune out potential vibration modes.

Power Conditioning (Converter)

Converter design choices tend to be influenced by the best solid state electronic component values currently available. Presently, for instance, 250 kW is a good modular size, which is likely to increase. Influenced by the different control requirements of the fuel cell stack and turbogenerator power loops, it is expected that the turbogenerator converter will be kept separate from the inverter or inverter array handling the fuel cell stack power output. The hybrid fuel cell power plant is likely to become a driving force in the advancement of cost effective large power conditioners (converters).

The present capacity of the Insulated Gate Bipolar Transistors (IGBTs) is a limiting factor to a single unit power conditioner. Other technologies such as gate turnoff thyristors (GTOs) are available but have inherent problems of lower efficiency and slower switching speeds when compared to the IGBT technology. Other emerging technologies, which require further study and development, include the MOS Turn-off Thyristors (MTOs) and the Integrated Gate Comutating Thyristor (IGCTs).

By 2010, the new IEEE electric grid interconnect standard (IEEE P1547) for distributed generation (currently in development) will likely require some modifications to the power conditioner in terms of additional protection and control requirements. It is envisioned the IEEE standard will require sweeping changes throughout the power conditioner industry as the industry moves toward a standard power conditioner configuration and away from each customer or contract having specific site performance requirements. The IEEE standard should help reduce the cost of the inverter performance and programming by minimizing the per contract engineering costs. At present, no power conditioner test protocol exists for testing the 3.8MW power conditioner. In addition, no manufacturer or third party testing organization is set up to full load test a power conditioner of this size. A test protocol and suitable test lab will have to be developed to accommodate the large power conditioner. Acceptance testing of the power conditioner will be critical to utility acceptance of the plant for reliability and safety reasons.

Power conditioner electrical efficiency presently at 95 percent must be improved to the 97.5 percent to improve the gas turbine generator output and the overall plant electrical efficiency.

Active Magnetic Bearings

Rolls-Royce Allison has proposed using magnetic bearings on the plant gas turbine generator. Magnetic bearings have several advantages, which include the following:

1. Long bearing life
2. Bearings are self-correcting to out of balance loads, which may arise through wear and tear or deposition.
3. No lubrication required (eliminates the need and weight of an entire lubrication system)
4. Reduced friction losses, as the only friction at bearings is air. (Reduced friction yields a more efficient machine)
5. The gas turbine is more reliable as the entire lubrication system has been eliminated, which can cause failure.
6. Bearings have inherent ability to reduce noise and vibration caused by rotor imbalance.

Active magnetic bearings (AMBs) with their associated control system inherently offers on-line monitoring and control of bearing forces and rotor displacements allowing early detection of faults. Further control system development work will be required in the programming and controls area to electronically locate the rotor position and to generate the current required for the magnetic bearings.

The control and stabilization of active magnetic bearings is now well understood and the gas turbine generator components can readily be designed to achieve good bearing performance without resort to new materials technology. This is because the bearings can be situated in a reasonably cool environment between 422 °K and 588 °K, which is compatible with normal electromagnet materials. AMBs are not yet widely in use, so some learning experience must be anticipated during the early embodiment.

Combustor

A low risk conventional combustor will be used in the firing of the Rolls-Royce Allison gas turbine generator. Several considerations affect the design choices for the combustor which appear below:

1. Because the combustor will be fueled for a short time, it should not be required to have ultra-low emissions. At maximum temperature rise, the NO_x emissions will be in the 100-150 ppm range but will decrease as the plant heats up.
2. As the fuel cells rise in temperature, the combustor delivery temperature is held constant requiring less fuel to burn. Combustor stability is required over a substantial range of fuel flow.
3. To avoid complicating the hot ducting, the combustor must remain in the main flow path even though it is not functioning. The pressure drop across the combustor must be minimized.
4. The combustor and associated ducting will have to be insulated in a thermal blanket to avoid overheating adjacent plant equipment.

Rolls-Royce Allison has recommended that a cylindrical three liner type combustor be used. The design point temperature rise is 866 to 921 °K based on plant startup conditions. The normal capability of a single liner system is to turn down by stable means to approximately one quarter of its design temperature rise (135-149 °K). The provision of three liners allows individual liners to be shut down, such that while the last operating liner is still producing a 167 °K rise, the whole flow average rise is only 55.5 °K, permitting a smoother transition from fired to unfired during startup. If it is determined that a larger step change is acceptable, then the system can be simplified to a single liner design. An alternate for further study is to utilize a catalytic element in the combustor in addition to multiple liner operation.

Gas Turbine Generator Control System

The gas turbine generator control system would be used to startup the gas turbine with a start signal from the plant control system. Once the gas turbine has been started, the fuel cell heated, and the combustor switched off, the gas turbine control system fuel control logic would become dormant. The gas turbine control system would control turbine speed and monitor turbine generator supervisory control. The plant control system through the turbine generator programmable logic controller (PLC) would take over the operation of the gas turbine generator to match the overall plant process requirements of the turbine compressor and expander sections. The coordination between the gas turbine controls and the plant control system still requires further development and understanding between Rolls-Royce Allison, M-C Power and Bechtel National.

Modeling work will also be required to determine the load following, load shedding and turndown of the generator and power conditioner. The response to electrical system transients such as loss of electric grid, ground faults in single phase or neutral, synchronization, and switch to island mode operation must be studied in more detail. Schemes for voltage control, current control, frequency control, power factor control and switching to and from voltage and current control modes quickly must also be studied.

Once the plant has reached the steady state performance, positive control of the turbogenerator running point will be primarily maintained in an asynchronous system by altering the DDA load characteristics. This requirement affects the electrical design of the generator and the associated power conditioning and electrical protection systems. The integration process is expected to require significant development time and capital.

3.A.1.c <u>Balance of Plant</u>

Much of the balance of plant (BOP) equipment (excluding the fuel cell and the gas turbine generator) has no design or development issues because the products available are considered to be mature. Specific pieces of equipment which will require additional design and development prior to use in the - 20 MW high efficiency pressurized molten carbonate fuel cell power plant appear below:

Recycle Blowers

At approximately 610 kPa operating pressure, only a limited number of blower manufacturers have the knowledge base and experience to properly design the recycle blower. The blower operates at a low pressure ratio, high temperature, and moderate pressure. The design issues resulting from the design constraints are as follows:

Shaft seals-The shaft seals must be designed to keep the higher pressure cathode gas from leaking out to atmosphere. Design, material selection, and endurance testing for design confirmation will be required.

Bearing design- The bearing design must accommodate the blower rotor high temperatures and the associated shaft thermal growth. Confirmation of the bearing and shaft design prior to the commercial unit will be required by shop testing of any proposed solution.

Materials of Construction- The materials selected for the blower housing, impeller, and shaft must be designed to prevent high temperature surface corrosion. This may be accomplished by the use of high temperature base materials or with protective spray coatings over a less costly base material. Endurance testing of the proposed materials must be verified by testing prior to installation in a commercial fuel cell power plant.

Power Module Vessel

Each power module vessel contains four (4) molten carbonate fuel cell stacks, four (4) reformer assemblies, and miscellaneous piping. Some of the design and development issues associated with the Power Module Vessel include the following:

Vessel Design-The design must accommodate the removal and reinstallation of the individual reformers and fuel cell stacks. Other requirements include the access requirements for maintenance and transportation of the vessel with equipment installed subject to weight and dimensional restrictions of land-based transportation. Wind loading, seismic loading, and transportation loading (lifting vessel assembly onto and from vehicle, and vessel stiffness to road potholes) design conditions must also be considered in the vessel design. Power module assembly methods and sequences must also be modeled and developed by the plant module fabricator prior to vessel fabrication commencement. A removal scheme for each fuel cell and reformer with special tooling required must be modeled and procedure developed prior to vessel fabrication. Nozzle orientations and allowable stresses must be studied and coordinated with both vessel interior and exterior piping. Electrical power and grounding connections to the power module components must be routed and designed to the ANSI/NFPA 70, ANSI C2, IEEE 80, and IEEE 142. The instrumentation must be designed to take the high internal vessel temperature and penetrate through the pressure vessel wall without leaks. A supporting vessel structure such as saddles, which controls the vessel thermal growth, must also be developed. With the vessel in operation containing both natural gas and hydrogen, a blast analysis study must be completed to specify and locate the appropriate blast pressure relieving devices. M-C Power will perform most of these tasks on the 450 kW demonstration plant power module vessel. The PDI 450 kW power module vessel will operate at 300 kPa pressure, which results in larger diameter vessel and piping than the HEFPP vessel. Lessons learned will be implemented in the HEFPP power module vessel.

Vessel Insulation Design- The vessel insulation must be studied to allow acceptable heat loss during plant operation at the lowest and highest ambient temperature. The insulation should also be designed for personnel protection from burns due to hot insulation or jacketing, where accessible by plant personnel. The insulation will also be designed to protect the vessel internal metal surfaces from condensation and to allow the use of carbon steel pressure vessel materials.

Piping design- The power module piping design must be studied to eliminate the use of control valves inside the pressure vessel. Manual valve usage inside the pressure vessel will be studied to minimize the number of valves. Pipe thermal expansion inside the vessel will be studied to eliminate the need for expensive expansion joints. High temperature, low-pressure-drop check valves located inside the hot pressure vessel will have to be developed and tested to keep the cathode blower power consumption low. In general the piping will be smaller but heavier wall for the HEFPP 600 kPa operating pressure when compared with the PDI 450 kW piping.

Inverter

The initial design plan is for one inverter to be provided for each power module. Four fuel cells in one common pressure vessel would feed one inverter. The fuel cells will be connected electrically in series. The inverter takes the DC power from the fuel cells and then boosts the DC voltage. Initial thoughts were to have the higher voltage DC power inverted to AC power at nominally 480 VAC. With 9 inverters and a net expected output from the inverters to exceed 17 MW, the electric bus connecting the inverters together becomes large due to the high current handling requirements. The 480VAC inverter output will have to be transformed up to a higher voltage to minimize large bus duct costs and grid connection costs. The present scheme is to have the inverter output voltage changed from 480 VAC to 4160 VAC. A study to determine the most economical bus and type of step-up transformer will have to be completed in the preliminary engineering phases. With the 9 inverters planned, a master synchronization and paralleling scheme for connecting the individual inverters to the grid and to the turbine generator power conditioner (converter) for startup and shutdown of the plant must be developed. The plant electrical islanding scheme and reconnection scheme must also be developed, which will allow the plant to operate in island mode and then synchronize with the grid without dropping load. The synchronization of the plant must occur within a very few cycles.

A study to determine the appropriate emerging inverter technology (Integrated Gate Commutating Thyristors (IGCTs), Insulated Gate Bipolar Transistors (IGBTs), MOS Turn-off Thyristors (MTOs) or Gate Turnoff Thyristors (GTOs)) prior to order placement will be required. In the study, efficiency, cost, footprint size, voltage capacity, current capacity, additional auxiliary equipment/system requirements, and switching speed will be evaluated to select the best available technology. An optimization study will also be required to minimize the number of inverters. A limiting factor for the optimization study will be the maximum AC voltage the selected inverter technology can handle in the high frequency pulse width modulation mode. The pulse width modulation (PWM) technology may be a limiting factor as the maximum rating of present PWM technology is 690 VAC. It is anticipated that by 2003, IGBTs will be available to handle up to 1200 VAC in the pulse width modulation mode.

The present inverter technology in the size range required for the high efficiency power plant yields 95 percent electrical efficiency. Further developments to improve the efficiency to 97 to 98 percent are required. The most significant efficiency improvement may come from the use of trench type IGBTs, which will cut the conduction losses by 50 percent. Another improvement may come from the use of advanced pulse width modulation (PWM) generation algorithms. Implementation of the new algorithms may reduce the IGBT switching losses by approximately 30 percent without sacrificing bridge performance characteristics. Higher grade magnetic materials can be used in the reactors and chokes to reduce the iron losses or reduce the copper losses via shorter mean turn lengths. Two tradeoffs for the higher grade magnetic materials include higher material and component fabrication costs and reduction in the number of available core suppliers.

Fuel cell currents exceeding 1500 ADC present a unique design challenge for the inverter. The bus bar and cable losses generated at this current level are significant and can be difficult to control. Methods to reduce the losses include a) use of less resistive materials, b) use of broader cross-sections, and c) shorter circuit lengths. All of the above methods will be employed to some extent to repackage the inverter and improve the overall electrical efficiency.

By 2010, the new IEEE P1547 Interconnection standard for distributed generation (currently in development) will probably require modifications to the inverter in terms of additional protection and control requirements. At present no standard exists to test the inverters of this size. In addition, no manufacturer has the in-house testing facilities to perform a full load test of the inverters envisioned. Acceptance testing of inverters will be critical to obtaining electric utility acceptance of the plant for reliability and safety reasons. Development of a test protocol and test facility either at the manufacturer or a third party is required.

Decisions on whether the turbine generator power conditioner or the fuel cell inverter will have the master synchronizer to the electric grid must be made. Initial thoughts on this matter include that the turbine generator power conditioner will be the master as it is the first piece of equipment to start and last to operate under normal conditions. Development of the synchronization scheme requires further work.

Reformer

The reformer will also require some development work primarily due to the change in pressure from 300 kPa (used on the PDI project) to the 600 kPa HEFPP operating pressure. Ishikawajima-Harima Heavy Industries (IHI) has developed a reformer for 1mPa operation for Japan MCFC projects and 300 kPa operation for Miramar. Operation at 600 kPa will require changes in the flow distribution path. Specific areas of change include piping (where pipe size will get smaller due to lower specific volume but pressure will require thicker pipe materials) and manifolding /plate spacing (where manifolds and plate spacing should get smaller due to lower specific volume). The reformer at 600 kPa operating pressure will also require some testing to confirm performance.

The HEFPP goal for reformer catalyst replacement is 10 years. IHI will develop and test their catalyst to obtain 40,000 HR life as part of the PDI project. Catalyst life is dependent on the amount of catalyst deposited per unit area on the reformer plates and the total plate area in the reformer. Some additional catalyst life development work will be required by IHI for the HEFPP project.

3.A.2. Confirmation of Design Parameters

3.A.2.a Fuel Cell

The MCFC stacks will be designed to operate at the following conditions for the HEFPP study:

Pressure (kPa)	605 (~6 atm)
Fuel utilization (per pass, %)	80.4
Current density (mA/cm^2)	200
Average cell voltage (mV)	758 (at the beginning of life).

When adjusted for operating conditions, this performance is close to the performance that has been achieved in bench-scale fuel cells at IGT and M-C Power. For example, fuel cell IM9705, tested at IGT for approximately 5,000 hours, had a voltage of 730 mV at 200 mA/cm^2 at 303.9 kPa (3 atm) and 75% fuel utilization at the onset of the test. Pressure was increased from 303.9 kPa to 605 kPa, which increased cell voltage by 35 to 40 mV; a fuel utilization increase from 75 to 80% reduced the voltage by 7-10 mV. Hence, cell voltage at the HEFPP conditions would be approximately 760 mV. M-C Power's fuel cell performance model also predicted that the performance required for MCFC stacks at the HEFPP is achievable.

Based on experimental data, model predictions, other published data, and M-C Power's performance improvement plan, this level of performance for MCFC stacks is obtainable.

The challenge is to achieve and maintain this level of performance at the full-area commercial-size stacks.

The following issues related to performance improvement are being addressed presently as part of the DOE funded PDI program:

1. Optimization of component pore matching and electrolyte distribution among components. Implementation of better pore matching will improve performance by reducing anode and cathode polarization. Adjusting the pore-size distributions and the wetting properties of the electrodes will improve pore matching.

2. Optimization of the cathode thickness and its porous structure. Because of the higher Li/Na ionic conductivity, the effective thickness of the cathode with Li/Na electrolyte is higher than that of a cathode operating with Li/K electrolyte. Increasing cathode thickness and increasing external agglomerate surface will improve cathode performance. Optimizing the cathode oxidation/lithiation reaction will result in 20-30 mV performance improvement.

3. Optimization of electrolyte composition. Comparison with the-state-of-the-art cell performance shows that the cell performance at 160 mA/cm^2 can be improved by 20-25 mV simply by the change of electrolyte composition. Another advantage of this alternate electrolyte is a reduced sensitivity of cell performance to the operating temperature, which results in a higher stack output and a lower stack maximum temperature.

4. Improvement of component manufacturing tolerances will result in: (a) more uniform flow distribution among cells and will allow the stacks to operate at 80+ % fuel utilization per pass and (b) uniform contact pressure distribution over the active area with reduced stack internal resistance.

5. An advanced plate design to reduce cost, ensure 100% sealing, lower electrolyte losses for corrosion, and improve uniformity of flow and pressure distribution.

The full-area commercial size stack performance will be verified via a comprehensive testing program that includes testing of 100-cm^2, 1000-cm^2, along with full-area cells and stacks.

3.A.2.b Gas Turbine Generator

Rolls-Royce Allison has investigated the critical design parameters associated with a 6.0 pressure ratio 3.8 MW class gas turbine-generator. Specific design parameters are addressed individually below:

Compressor

Up to a pressure ratio of approximately 6, axial and radial machines give similar performance between inlet and diffuser exit (at 0.15 Mach number). In the study analysis, a seven stage axial compressor was 0.6 percent more efficient than a single stage radial compressor. Above this pressure ratio, the radial compressor efficiency deteriorates when compared to the axial compressor due to rising Mach number effects in the single radial stage. The maximum radial stage pressure efficiency is normally limited by metal strength properties (maximum pressure ratio of 6.5 for steel and 8 to 9 for titanium). Radial compressors offer a large reduction in number of parts and cost for a given pressure ratio. At a pressure ratio of 6, the most cost effective compressor design results in a single steel stage radial compressor. It should be noted that the radial compressors have not been produced in aeroderivative gas turbines for many years. The radial compressor will have a large scroll diameter approaching 1.5 meters. In developing the radial compressor design, the following design parameters were used:

1. Inlet hub/tip radius ratio will be set to 0.4 to avoid extreme airfoil geometry (also allows for bearing if desired)
2. Inlet tip radius is designed to avoid exceeding a 1.0 inlet Mach number relative to the blades.
3. The rotor tip radius is adequate to generate the design pressure ratio at appropriate loading.

Turbine

In the HEFPP, turbine gas flow will be delivered from the fuel cell to the gas turbine generator by a circular pipe. Hot process gas from the fuel cell is transferred to the axial turbine inlet through a carefully shaped volute in which the design and fabrication processes have been used many times by Roll-Royce Allison. Delivery of gas from the volute is designed to be at a fixed swirl and axial velocity components to maintain a constant nozzle guide vane entry angle. The tangential component of the velocity serves to partially offload the vanes. By taking the principle too far, the resultant will lead to large volute velocity and potential wall scrubbing losses. It is therefore desirable and efficient to retain a row of guide vanes for the turbine section.

The turbine inlet temperature of 704°C is low enough to allow the use of low cost materials and allows elimination of turbine wall cooling temperatures.

The single shaft design turbine generator imposes a lower speed limit than preferred for the compressor. The reasons for this are as follows:

1. The volumetric flow leaving the turbine is 2 to 2.5 times larger than that entering the compressor because the exhaust temperature is higher. (If a stage hub/tip radius ratio of 0.5 is

used, the last turbine blade tip radius is approximately 1.5 times that of the first compressor blade which gives a correspondingly higher tip speed.)
2. The power turbine tips normally have to carry shrouds for maximum efficiency.
3. The turbine blades are hotter.

The axial turbine design criteria used are as follows:

1. Minimize the turbine stages required for each duty.
2. Keep the stages at moderate internal Mach number and loading to retain high efficiency.
3. The final stage exit area should yield an axial Mach number of 0.35. Diffuser losses should be kept at no greater than 40 percent of dynamic head, which yields a maximum 3 percent total pressure loss.
4. The highest rotational speed should be selected based on the selected material properties.
5. The exit hub/tip radius ratio should be kept between 0.5 and 0.6 to avoid local aerodynamic problems and provide sufficient space for structure. (Note: this now fixes the last stage hub and tip radius.)
6. Airfoils with high aspect ratio should be used to give good efficiency and low shroud stress. The aspect ratio should also be low enough to limit the blade count (cost) and avoid excessively thin sections or steep annulus angle. This criteria determines the stage axial lengths.

At a pressure ratio of 6, it was found that the preferred design RPM for a single stage radial compressor of 13,200 was acceptable when paired with the maximum desired value of the axial turbine. An axial compressor does not offer a significant efficiency advantage for this cycle.

For higher pressure ratio cycles, the tip speed of the radial turbine stage has to be increased (approximately 20% for a 10 pressure ratio machine) and this moves it into a region where it experiences shock losses. More efficient units can be created using either all axial or hybrid axi-centrifugal multistage designs. In order to keep the minimum number of stages, relatively high speed is still required. The speed limiting feature in a single shaft machine is normally the last stage turbine blade hub radial stress. The level of stress can be shown to be fixed by the blade swept area and the RPM. The swept area is set by the air flow amount, its exit temperature, and the requirement for an axial Mach number not exceeding 0.35.

For cycle options above 6 pressure ratio, it was found that single shaft configuration RPM is limited by turbine last stage stresses. This is just acceptable for a 10 pressure ratio radial compressor of lower efficiency (due to shock losses), but leads to the need for more stages in a more efficient axial or axi-centrifugal machine. Without RPM compromise, a (3 stage axial + 1 stage radial) hybrid machine is acceptable for 10 pressure ratio, but, when slowed to turbine-acceptable speed, (6 axial stages + 1 radial stage) is required. Although this represents a cost penalty to a single shaft configuration, the six axial stages/1 radial stage configuration remains the preferred scheme because of its merits of flow control for power turndown and resistance to load shed overspeed. In addition, pure axial compressors of appropriate speed are already in production, offering cost-effective solutions for a larger size fuel cell plant.
Given that the turbines are running near to the stress limited speed, the number of stages can be minimized. Two stages are necessary for the 6 pressure ratio cycle and three stages are required

for the 10 and 14 pressure ratio cycles respectively. It is highly unlikely that a low cost single stage radial turbine would give good results in the 6 pressure ratio cycle (at only 977 R inlet temperature, the loading would be greater than optimum) and would be unsatisfactory for the higher pressure ratio cases.

All the axial turbines proposed for the three pressure ratio levels are predicted to yield efficiency between 91 and 92 percent.

Alternator

Several options were considered for the alternator including the following:

1. Compressor, turbine, and asynchronous alternator on a single high speed shaft.
2. Compressor and turbine on one shaft with a gearbox driving an asynchronous alternator at 6000 RPM
3. Compressor and drive turbine on one shaft. Power turbine and asynchronous alternator on a second somewhat slower shaft.
4. The compressor and turbine on one shaft with a gearbox driving a conventional synchronous alternator at synchronous speed.
5. Turbine and compressor on separate shafts running at their individual best speeds geared to a synchronous alternator at synchronous speed.

In the first three options, the asynchronous generator would have to be connected to a power conditioner to produce the desired 60 Hz power. The power conditioner has losses associated with the conversion of high frequency power to 60 Hz power of 3 to 4 percent. In options three and four, the generator is synchronous and operates at 60 Hz power, but has the additional gearbox losses, which will reduce the overall turbine generator efficiency by 3 to 4 percent. The geared units also require a lubrication system to keep them operating properly, which may be eliminated with a single common shaft turbine/compressor/asynchronous alternator utilizing magnetic bearings.

The options were also evaluated economically in terms of first cost. The economic choice was the compressor, turbine, and asynchronous alternator on a common shaft option, as the assembly was the lightest of all the options. The geared options have additional weight and cost associated with the gearbox, lubrication system, and the generator. Reductions in speed, force the turbine, compressor, and generator to become larger.

Option 1 has some drawbacks in that the direct drive alternator in the 3.8 MW size range must be scaled up from existing technology presently at the 75 kW level or derived from the high speed motor technology. For more detailed information, please refer to the Design and Development Section 3.A.1.B.

Power Conditioner

With the direct drive alternator, a power conditioner or inverter must be used to convert the high frequency AC power to DC power and then back to 60Hz AC power. Several technologies exist or are in development such as insulated gate bipolar transistor (IGBT), gate turn-off thyristor (GTO), MOS turnoff thyristor (MTO), and integrated gate comutating thyristor (IGCT). The IGBTs are limited to approximately 250 kW single unit size but can have several units placed in parallel on each of three phases to meet the desired power output. The largest paralleled power conditioner in use today is 1.5 MW in capacity used in windmill applications. GTOs may also be used but suffer from slower switching speed and lower efficiency when compared to the IGBT technology. GTOs allow higher current and voltage to be used when compared to the IGBT technology. MTO and IGCT are still being developed but hold promise as the technology of the future. For further discussion, please refer to the Design and Development Issue Section 3.A.1.B.

Magnetic Bearings

Active magnetic bearings (AMBs) have been selected by Rolls-Royce Allison for use on the proposed gas turbine generator. The AMBs feature reduced friction losses, long bearing life, self correction to out of balance loads, noise reduction, and require no lubrication when compared to conventional lubricated bearings. AMBs are well understood, but will require some development work in the programming and controls required to electronically locate the rotor position and to generate the currents required for the magnetic bearings. For more information, please refer to the Design and Development Issue Section 3.A.1.B.

Combustor

In regular aero-derivative turbine generator practice, a 4 percent pressure loss from the compressor diffuser outlet to turbine inlet is required to serve the following purposes:

1. To drive the high velocity dilution air jet streams into the final combustion zones to ensure complete combustion and provide proper mixing within a short length.
2. To ensure that the cooling flow passed to the first turbine blade row is at a higher pressure than the very hot gases impinging on the turbine blade leading edge. This permits the formation of leading edge cooling films on the blade.

With the molten carbonate fuel cell power plant, the turbine generator combustor is different as follows:

1. There is more space for mixing.
2. There is no need to cool the turbine blades as operating temperatures of approximately 700 C are expected which is well below the much higher conventional temperature aeroderivative combustors.
3. The combustor is used only unit startups and transients but most of the pressure losses are always present when not in operation.
4. Weight and operating volume do not have to be minimized.
5. No requirement for very high wall temperatures or cooling air.

The preliminary sizing of the combustor components yields a low velocity unit of around 2 feet diameter burning zone and approximately 5 feet length. This combination gives an unfired pressure loss of 1.5 to 2 percent. The parameters mentioned above place the combustor well within the range of conventional duct burner technology.

3.A.2.c **Balance of Plant**

The next tasks are to establish the equipment design parameters and to select the process operating conditions. Equipment manufacturers provided the equipment design parameters. Table 1 lists the equipment design parameters and operating conditions for the major subsystems.

The selection of operating conditions is based on achieving the highest natural-gas-conversion efficiency for the plant. The following high-efficiency prerequisites directed the process-simulation search for the optimum operating conditions:

- high conversion of natural gas to H_2-rich fuel
- high conversion of H_2 fuel to electricity in the MCFC
- high conversion efficiency for H_2 chemical energy to electrical energy
- minimize fuel combustion
- high efficiency bottoming cycle

The key operating conditions are listed in the following Table:

Full-Load, Start of Run (SOR) Operation – 15°C Ambient Air, Sea Level	
System Pressure	610 kPa
Steam Temperature	536°K
Anode-Recycle Flow, weight ratio	3:1
Steam:HC-Carbon, mole ratio	4.7:1
Reformer-Inlet Temperature	799°K
Reformer Outlet Temperature	1,061°K
Anode Inlet Temperature	950°K
Cathode Inlet Temperature	978°K

Selection of Optimum Operating Conditions

The effects of key-equipment operating conditions on equipment performance and the natural-gas-conversion efficiency are discussed below.

System Pressure

The effect of system operating pressure on plant performance is discussed in Section 3.A.3.

Steam Temperature

Increasing the steam temperature results in a slight increase in power output from the gas-turbine generator - just over 1% increase for the steam temperature range 480-560°K. However, any increase in superheat is at the expense of steam flow (since steam is generated in a non-fired heat recovery steam generator (HRSG) unit), and reducing steam flow affects methane conversion in the reformer, leading to lower overall efficiency.

Steam Flow Rate

The steam flow rate to the reformer is an important determinant of the natural gas conversion. This variable plays an important role in determining the natural-gas-conversion efficiency.

The steam flow rate must be above the minimum needed to prevent carbon formation in the reformer and provide a safe margin to carbon formation in the anode. For this design, the steam flow rate is the maximum steam flow that can be generated, at 900 kPa and 536°K, from the gas turbine exhaust, without fuel firing.

As mentioned above, higher methane slip from the reformer results in more fuel combustion in the reformer combustor. When there is sufficient H_2 and CO in the anode exhaust to provide the reformer duty, the combustion of residual methane serves no other purpose than participating in the gas turbine power cycle. Therefore, under these circumstances, residual methane lowers the overall natural-gas-conversion efficiency, and must be minimized.

The steam flow rate also determines the quantity of anode recycle to the reformer.

Reforming Temperature

High reforming temperatures - i) increase methane conversion, ii) require more residual fuel in the anode exhaust to meet the reforming heat duty (lower plant efficiencies), and iii) requires more expensive materials of construction. The operating temperature is selected by careful consideration of the materials of construction and the values for other process variables affecting methane conversion (pressure, steam flow rate).

For this design, the low operating temperature is offset by high steam flow to the reformer and low operating pressure. The low reforming temperature means that the reformer can be fabricated from stainless steel.

Anode Recycle

Anode recycle improves flow distribution in the anode, facilitates thermal management, and lowers per-pass fuel utilization in the anode compartment. By introducing the recycle stream upstream of the reformer, the additional water content in the recycle gas helps with the conversion of natural gas to hydrogen-rich fuel.

Anode recycle improves the basic design concept in three important process areas. First, as mentioned, recycling exhaust gas from the anode compartment increases the amount of steam flowing to the reformer. Second, recycling anode exhaust results in an increase in the quantity of hydrogen entering the anode compartment. Therefore, for a fixed fuel conversion, the per-pass fuel utilization is lower. Third, anode recycle helps with the thermal management of the stack.

Higher concentrations of CO_2 and H_2O in the anode feed, as a result of recycling anode exhaust, should lower the stack operating voltage - through the Nernst term in the reversible cell potential equation. However, for the same high fuel conversion without anode recycle, the severely depleted H_2 concentration at the anode exhaust lowers the exit reversible potential significantly.

Since electrodes are iso-potential surfaces, the cell potential, for co-flow designs, is set by its exhaust value.

For the same fuel conversion, the per-pass fuel utilization increases from 80% with recycle, to 94% without recycle. To maintain 80% fuel utilization without anode recycle, the steam flow to reformer has to be increased. Raising additional steam means fuel has to be fired either in the turbine combustor or in the HRSG unit. Raising the additional steam lowers the natural-gas-conversion efficiency from 70% to 63%.

Increasing the reformer outlet temperature from 1,060°K to 1,117°K, in an attempt to increase the methane conversion at reduced steam addition, lowers the efficiency to 61%.

The amount of anode recycle is set by the pre-reformer temperature limitation. Increasing the recycle-to-steam flow weight ratio beyond 3:1 causes the temperature to exceed the pre-reformer catalyst maximum operating temperature.

Anode Inlet Temperature

The anode feed gas must be hot enough to keep the electrolyte in a molten state. The anode feed gas temperature must be above the Boudouard carbon formation temperature.

Cathode Inlet Temperature

Like anode feed gas, the cathode feed gas temperature must be sufficient to keep the electrolyte in a molten state.

Cathode Outlet Temperature

Stack cooling, by an external, gas recycle around the cathode, is responsible for the main auxiliary power demand. Recycle flow, and hence recycle blower horsepower, is minimized by operating between the minimum inlet temperature of 866°K and the maximum outlet temperature of 978°K.

High operating temperatures are needed to achieve lower electrolyte conductivity, which minimizes Ohmic resistance losses and consequent heat generation.

Vessel Heat Loss

The power module vessel is insulated to minimize heat loss. The argument for minimizing heat loss was made above.

TABLE 1
Major Subsystem
Design Parameters and Operating Conditions
Site Elevation-Sea Level

	Start of Run SOR	End of Run EOR
Fuel Processor - Reformer	Type: External/Separate - IHI Gas-Heated Plate-Type	
Steam:Hydrocarbon ratio	4.68	5.3
Steam:Total Carbon ratio	1.43	1.5
Operating Pressure, kPa	606	606
Exit Temperature, K	1,061	1,061
Process Duty, kJ/h	1,018,806	1,026,361
Number of Units	36	36
Fuel Cell Stack Design	Type: MC-Power Molten Carbonate, Co-Flow	
Operating Pressure, kPa	605	605
Current Density, mA/cm2	200	200
Cell Voltage, mV	758	700
Power Density, kW/m2	1.52	1.40
Fuel Utilization - per pass, %	80.4	80.3
Fuel Utilization - overall, %	86.2	86.5
Number of Stacks Required	36	36
Inverter Design	Type: Solid-State	
Input Voltage, Volts	227	210
Input Current, Amps DC	2,180	2,180
Output Voltage, Volts	4,160	4,160
Output Electric Power, kW	479	443
Power Conversion Efficiency, %	97.5	97.5
Number of Units Required	9	9
Recycle Gas Blower		
Adiabatic Efficiency, %	75	75
Differential Pressure, kPa	6.2	6.2
Shaft Horse Power, kW	108	119
Motor Efficiency, %	92	92
Number of Units	3	3
Gas Turbine Design	Type: Rolls-Royce Allison	
Compression Ratio	6.16	6.16
Compressor Air Flow, kg/s	16.81	19.19
Compressor Efficiency, %	84	84
Turbine Efficiency, %	91.9	91.9
Generator Efficiency, %	98.5	98.5
Net Power Production, kW	20,115	19,159
Overall Electrical Efficiency	70.11	66.78

TABLE 2
Performance Summary
Site Elevation – Sea Level

~~Start-of-Run Operation~~

Ambient Temperature, °C	15	-29	49	49
Relative Humidity	60%	0%	0%	100%
AC Power from Power Modules, kW	17,256	17,256	17,256	17,256
AC Power from Gas turbine Generator, kW	~~3,429~~	~~3,603~~	~~3,246~~	~~3,242~~
Gross Power Production, kW	**20,685**	**20,859**	**20,502**	**20,498**
Auxiliary Loads, kW	570	571	571	563
Net Power Production, kW	**20,115**	**20,288**	**19,931**	**19,935**
Natural Gas Consumption, kJ/h (LHV)	1.0328E+08	1.0328E+08	1.0328E+08	1.0328E+08
Fuel Fired in Gas Turbine, kJ/h (LHV)	0	0	0	0
Fuel Fired in HRSG, kJ/h (LHV)	0	0	0	0
Overall Electrical Efficiency (LHV), %	**70.11**	**70.72**	**69.47**	**69.49**

TABLE 3
Performance Summary
Site Elevation – 5,000’

~~**Start-of-Run Operation**~~				
Ambient Temperature, °C	15	-29	49	49
Relative Humidity	60%	0%	0%	100%
AC Power from Power Modules, kW	17,256	17,256	17,256	17,256
AC Power from Gas turbine Generator, kW	~~3,099~~	~~3,368~~	~~2,819~~	~~2,845~~
Gross Power Production, kW	**20,355**	**20,624**	**20,075**	**20,101**
Auxiliary Loads, kW	570	571	571	563
Net Power Production, kW	**19,785**	**20,052**	**19,504**	**19,538**
Natural Gas Consumption, kJ/h (LHV)	1.0328E+08	1.0328E+08	1.0328E+08	1.0328E+08
Fuel Fired in Gas Turbine, kJ/h (LHV)	0	0	0	0
Fuel Fired in HRSG, kJ/h (LHV)	0	0	0	0
Overall Electrical Efficiency (LHV), %	**68.96**	**69.90**	**67.98**	**68.10**

TABLE 4
Performance Summary
Site Elevation – Sea Level

~~**End-of-Run Operation**~~

Ambient Temperature, °C	15	49
Relative Humidity	60%	0%
AC Power from Power Modules, kW	15,946	15,946
AC Power from Gas turbine Generator, kW	~~3,821~~	~~3,595~~
Gross Power Production, kW	**19,767**	**19,541**
Auxiliary Loads, kW	608	610
Net Power Production, kW	**19,159**	**18,931**
Natural Gas Consumption, kJ/h (LHV)	1.0328E+08	1.0328E+08
Fuel Fired in Gas Turbine, kJ/h (LHV)	0	0
Fuel Fired in HRSG, kJ/h (LHV)	0	0
Overall Electrical Efficiency (LHV), %	**66.78**	**65.99**

3.A.3. Optimum Operating Pressure Study

After establishing the design concept, the BOP equipment configuration, and equipment design parameters, the next priority is to select the system operating pressure. In this study, pressure selection is based on process performance. i.e., the pressure, which results in the highest natural-gas-conversion efficiency, is selected.

Feed Stream Conditions

Per the study basis, process streams delivered to the battery limit are either at some nominal supply pressure, or else ambient pressure.

- Natural gas is supplied at 205 kPa, and has to be compressed to the system pressure.
- Ambient air, the oxidant and cooling streams in the fuel cells, is compressed to system pressure by the gas turbine compressor.
- Finally, steam is supplied to the power modules above system pressure, since steam is the motive fluid for the recycle gas ejector.

Three system pressures were considered: 600 kPa, 1,000 kPa and 1,400 kPa. These pressures cover the pressure-ratio ranges for aero-derivative gas turbines proposed by Rolls-Royce Allison.

Process simulations of the proposed design concept (power module, gas turbine, and HRSG unit) were performed at the different operating pressures, with equipment performance characteristics provided by equipment suppliers.

Effect of Pressure on Power Generation Efficiency

1) MCFC Stacks

The efficiency at which an MCFC stack converts chemical energy to electric power is directly proportional to the ratio of potential developed to the open circuit voltage. The Nernst equation defines the relationship between the cell's reversible potential and reactant partial pressures. An increase in system pressure results in an increase in cell potential. In addition, higher pressure enhances mass transfer and reaction kinetics at the electrodes, helping reduce the overpotentials - thereby increasing the operating voltage. The MCFC efficiency increases from 59% to 61% as the pressure is increased from 600 kPa to 1400 kPa.

Other Effects of Pressure

In addition to the above, system pressure affects the design and operation of MCFC stacks in several other ways.

Stack Pressure Drop

For a fixed cell configuration and stack design, higher pressure reduces the pressure loss for the fuel and oxidant streams. Low pressure drop is especially important for the flow of oxidant/cooling gas to the cathode compartments. A motor-driven blower delivers this stream to the cathode compartments and recycles cathode exhaust back to the blower as part of the stack cooling process. The power requirements for the recycle blower are reduced significantly at higher operating pressures.

Cathode Dissolution

High CO_2 partial pressures can lead to nickel dissolution at the cathode – eventually leading to degradation of the cathode.

Carbon Formation

If carbon formation at the anode inlet occurs by the Boudouard reaction, then, since this reaction is favored by high pressure, the Boudouard carbon formation point moves closer to the operating condition of the anode feed gas. i.e., the safety margin between the anode inlet gas temperature and Boudouard carbon formation is reduced.

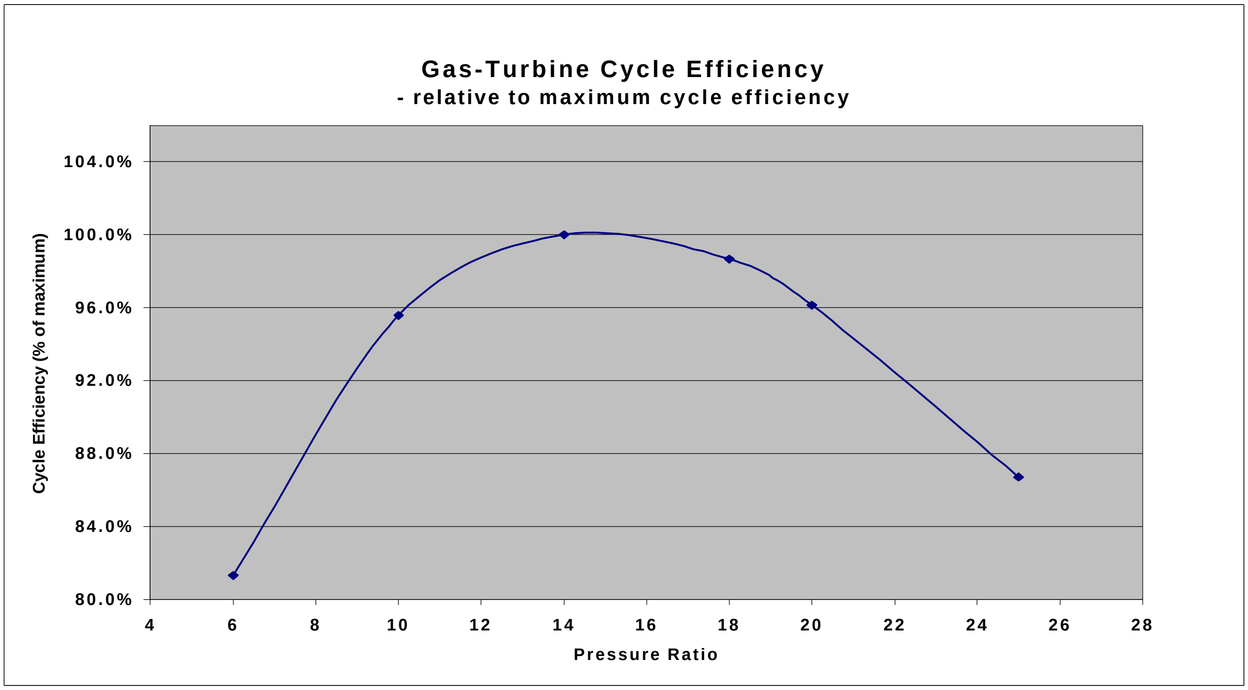
Electrolyte Vaporization

Since the carbonate evaporation rate is inversely proportional to the CO_2 partial pressure, loss of electrolyte through vaporization is reduced at higher pressures.

2) Gas-Turbine Generator Set

The cycle efficiency for the HEFPP gas turbine generator, relative to its maximum, is shown in Figure 1. The performance as a function of pressure ratio is based on a gas turbine operating as the “unfired” bottoming cycle to a MCFC power module (with fixed steam and natural gas flows) and for a fixed amount of waste heat available from the power modules.

FIGURE 1



From the figure above, the gas-turbine cycle maximum efficiency (ratio of net power produced to heat input[1]) occurs in the pressure-ratio range 12-16[2].

As mentioned above, the HEFPP plant is expected to achieve maximum natural-gas-conversion efficiency when the MCFC stacks and the gas turbine are both operating at their maximum cycle efficiencies.

From the figures above, the optimum operating pressure appears to be somewhere in the range 1,000-1,600 kPa. However, this is an incomplete assessment, for, when the MCFC and the gas-turbine are integrated with BOP equipment a different picture emerges as discussed below.

Turbine Exhaust Temperature

For simple gas turbine cycles, the higher the pressure ratio, the lower the turbine exhaust temperature. For a 978 °K turbine inlet temperature, pressure ratios of 10 and above lead to turbine exhaust temperatures that are too low to preheat natural gas to the desulfurization temperature and too low to raise the process steam requirements. Simply put, as the system pressure increases above 600 kPa, the turbine exhaust has insufficient energy at the right temperature level to meet the process heating requirements.

---

[1] Power module waste heat is held constant.

[2] As the pressure ratio tends to 1 the net work tends to zero. At the maximum pressure ratio, where the compressor discharge tends to the turbine inlet temperature, the net work also tends to zero.

Turbine Exhaust Temperature, @ 978 °K inlet temperature			
Pressure Ratio	6	10	14
Exhaust Temperature, °K	670	593	547

Above 600 kPa it is necessary to fire fuel in either the turbine combustor or a HRSG duct burner. This effect is made worse by the steam saturation temperature, which increases as the system pressure (and therefore the steam pressure) increases.

Fuel combusted in either the reformer combustor or the gas-turbine combustor can only be converted to electric power through the gas-turbine cycle, at its cycle efficiency.

Consequently, for the concept proposed for the HEFPP demonstration plant, higher operating pressures result in lower overall electrical conversion efficiencies. Therefore, 610 kPa operating pressure was selected for the system design.

A summary of plant performances at different system operating pressures is shown in Table 5.

Effect of Pressure on BOP Systems

The following is a summary of the effects of system pressure on BOP equipment.

<u>Natural Gas Compressor</u>
Power consumption, design complexity, and cost for the natural gas compressor increase with increasing operating pressure.

<u>Steam System</u>
Increased system operating pressure means that steam for the ejector and fuel processor has to be raised at higher saturation temperature. However, increased system pressure results in lower turbine exhaust temperatures. Above 600 kPa, these two temperatures diverge from one another, making it necessary to combust fuel to redress the situation.

<u>Fuel Processor</u>
Increased operating pressure reduces methane conversion in the reformer. With increasing pressure, the target conversion is achieved either through higher reforming temperatures and/or increased steam flow. Otherwise, lower conversion has to be accepted, and the natural gas feed has to be increased. For 1,000 kPa and 1,400 kPa operating pressures, increasing the steam supply proved to be more efficient than accepting lower natural gas conversions by approximately 1% in natural-gas-conversion efficiency.

Any unconverted methane passes through the anode compartment to the reformer combustor, where it is combusted along with unconverted MCFC fuel (H_2 and CO). If there is sufficient H_2 and CO in the MCFC anode exhaust (flowing to the combustor) to supply the reformer heat duty at the correct temperature levels, then combustion of unconverted methane serves no other purpose than to generate power through the gas-turbine cycle, and should be avoided, or minimized.

Therefore, as far as the fuel processor is concerned, higher pressure operation tends to reduce natural-gas-conversion efficiency – either through increased methane slip, or from additional energy requirements to operate the reformer at higher temperature and/or to provide additional steam.

Recycle Blower

At higher system pressures the recycle blower has lower volumetric throughputs and has to develop less differential head. The net effect is to lower the plant auxiliary load.

Power Module Vessel

The operating pressure of the power module vessel is effectively the same as the system pressure. For the same diameter vessel (fixed equipment and piping sizes), higher pressures lead to thicker vessel walls. Higher pressures also lead to hotter purge air from the compressor. For a pressure ratio of 14:1 and an ambient temperature of 49°C, the vessel purge air temperature is close to 700 °K. These temperatures present additional design challenges for equipment instrument cables and vessel design temperatures.

Power Module Equipment Heat Loss

Power module equipment inside the vessel and the vessel itself are both thermally insulated to minimize heat loss – see discussion above.

TABLE 5
HEFPP Performance Summary
At Different Operating Pressures

Operating Pressure, kPa	**610**	**1010**	**1420**
Cell Voltage, mV	758	771	785
Per-pass Fuel Utilization, %	80	80	80
Cell Efficiency, %	59.1	60.2	61.2
Cathode-Inlet CO2 partial pressure, kPa	54	85	112
Reformer - Feed Methane Conversion, %	98.2	97.2	94.7
Steam Pressure, kPa	896	1,303	1,710
Saturation Temperature, K	448	465	478
BFW Consumption, kg/h	5,899	6,199	5,838
Compression Ratio	6.2	10.2	14.3
Compressor Discharge Temperature, K	518	603	666
Gas Turbine N.G. Fuel, kJ/h (LHV)	-	1.433E+07	2.072E+07
Gas Turbine Inlet Temperature, K	978	1,124	1,167
Gas Turbine Exhaust Temperature, K	671	698	674
Number of Power Modules	36	33	30
MCFC Stack Power Output, kW	17,157	15,380	14,487
G.T. Generator Power Output, kW	3,409	5,043	5,943
Auxiliary Power Consumption, kW	353	124	65
N.G. Compressor Power Consumption, kW	213	299	365
Net Power output, kW	20,000	20,000	20,000
N.G. Fuel to G.T. Combustor, kg/h	-	313	453
N.G. Feed to Steam Reformer, kg/h	2,244	1,988	1,895
Total N.G. Fuel Consumption, kJ/h (LHV)	1.027E+08	1.053E+08	1.074E+08
Overall Conversion Efficiency (LHV), %	**70.1%**	**68.4%**	**67.0%**

3.A.4. Optimum Number of Spare Trains for Each Major Process Area

To perform maintenance on any power module component, the power-module vessel has to be depressurized. The number of power modules contained in a single vessel is a compromise between vessel size, number of vessel penetrations, transportation limitations, and the power-loss burden to maintain, or replace, a single power module. With four power modules per vessel the power reduction incurred by taking a single vessel off-line is 11%. Similarly, loss of a single fuel cell inverter will reduce the plant output by 11% and force the power module vessel to be shutdown.

With four modules per vessel and thirty-six modules required for a 20 MW facility, there is a total of nine power-module vessels.

A single recycle blower serves three power-module vessels (12 power modules). This creates three power trains. Shutdown of a single blower results in the shutdown of its power train, and the loss of one-third of plant capacity.

Because of the modular nature of fuel cell power generation, there is appreciable manifolding and sub-manifolding required to distribute feed, exhaust, and utility streams to and from all the power modules.

An alternative arrangement is to locate all power modules inside a single, field-fabricated vessel. The advantages to this are: economy-of-scale cost reduction for the vessel, distribution to equipment is made inside the vessel (fewer vessel penetrations), most of the high-temperature piping is inside the vessel and therefore less insulation is needed, and piping design pressures and flange ratings can be lower. The main disadvantage is the need to shutdown the entire facility in order to maintain equipment inside the stack.

3.B System Definition

3.B.1 Process Description

Please refer to the Process Flow Diagram in Section 3.B.3 for better understanding of process.

Natural Gas Supply & Conditioning

Two, 100% capacity, motor-driven compressors (one operating, one standby) boost the natural gas from supply pressure to system operating pressure, 749 kPa. A heat-exchange coil in the HRSG unit preheats the pressurized natural gas to desulfurization temperature, 616 °K. Natural gas desulfurization takes place in a cylindrical vessel packed with zinc oxide. Following desulfurization, the natural gas splits into three equal streams - each stream flowing to one of the three MCFC power trains. Each power train contains three power module vessels, and each vessel contains four individual power modules. Natural gas is distributed to each of the power modules (thirty-six total).

Steam Supply & Conditioning

Demineralized boiler feed water (BFW) is supplied to the plant battery limit. An economizer coil (also inside the HSRG unit) preheats demineralized BFW before it enters the deaeartor. The deaerator strips the BFW of dissolved oxygen by contacting it with steam, over trays or packing. Deaerated BFW has a residual oxygen concentration of 5ppb. BFW is then pumped through the BFW heater to an elevated steam drum, where steam is generated by natural circulation. Saturated steam leaves the steam drum and goes to a superheater where the steam is superheated. The superheated steam leaves the superheater and is distributed to the individual power modules.

Power Module

A single power module consists of a fuel processor (reformer), its supporting equipment, and a 500-kW MCFC stack. There are thirty-six power modules in total.

Power Module Vessel

Each power module vessel contains four separate power modules. The power module vessels are pressurized to the system operating pressure, i.e. the operating pressure of the fuel processors and the fuel-cell stacks. A small flow of compressed air simultaneously purges the vessel and maintains vessel pressure. The air stream flows from the vessel to the process side of the power module, and prevents combustible gases from accumulating inside the vessel in the event of an equipment leak. The fuel cells are connected electrically in series. A single power module vessel provides power for one inverter which is located externally, but adjacent to the vessel.

Fuel Processing

Natural gas is converted to a hydrogen-rich fuel stream by steam reforming. IHI will utilize a similar plate type reformer which has been used successfully on the 250 kW Test Facility at Miramar.

Anode Recycle (Ejector)

Recycling part of the anode exhaust through an ejector creates a recycle flow between the MCFC stack and the fuel processor. Steam flow to the individual power modules is the motive fluid for the ejectors.

The steam-anode exhaust stream from the ejector is mixed with natural gas and then preheated to 919 °K by heat exchange with the hydrogen-rich fuel stream leaving the reformer.

Pre-reformer

The pre-reformer starts the steam-reforming of the feed hydrocarbon, only under adiabatic conditions. The process stream temperature drops from 919 °K to 799 °K as 23% of the methane in the feed is reformed.

Reformer

The reformer is a plate-type design of alternating reforming and heat transfer sections.

The partially reformed feed stream from the pre-reformer enters the IHI plate-type steam reformer where it is fully reformed to the hydrogen-rich product stream. The operating conditions at the reformer exit are 606 kPa and 1,061 °K.

The source of energy needed to sustain the reforming reactions is provided from combustor exhaust gas as it flows through the heat transfer sections of the reformer. The anode exhaust gas not recycled to the reformer is fed to the catalytic combustor, where residual CH_4, CO, and H_2 are combusted to provide the temperature and flow conditions necessary to transfer heat to the reformer.

Hydrogen-rich fuel from the reformer (reformate) is cooled to the fuel cell anode feed temperature in the reformer feed/effluent heat exchanger. The reformate then is piped to the fuel cell anode inlet.

Molten Carbonate Fuel Cell (MCFC)

The fuel and oxidant are consumed by charge transfer reactions in the MCFC stack. The reactions cause a potential difference between electrodes.

Anode

The hydrogen-rich fuel enters the anode at 950 °K, undergoes oxidation charge transfer reactions at the gas/electrode/electrolyte interface, and leaves the stack at 978 °K. Carbonate ions from the electrolyte are converted to carbon dioxide at the reaction sites, and leave the stack in the anode exhaust stream.

The stack consists of a number of cells arranged in parallel. Anode feed gas is distributed uniformly to each cell by the inlet manifold. Uniform distribution across the plate surface is achieved by providing channels in the anode compartment for the gas to flow through. Gas exiting the cell is collected in the outlet manifold.

At start-of-run conditions the cell voltage is 757 mV and the average current density is 200 mA/cm2. The cells are electrically connected in series, and therefore the stack develops practical voltages.

Cathode

The cathode feed stream comes from the three recycle blowers. Each cathode recycle blower feeds three power module vessels for a total of 12 fuel cells. The feed into each cathode blower is a mixture of three streams. The first is reformer flue gas which for a single recycle blower is collected from the 12 reformers (total) in the three power module vessels. The second stream added before the cathode recycle blower inlet is the cathode exhaust recycle gas. The third stream added before the cathode blower inlet is the air from the gas turbine compressor section. The air provides an oxidant supply and the fuel cell stack cooling. The first two streams, when mixed together, provide a source of carbon dioxide to replenish the electrolyte after carbonate ion oxidation at the anode. The cathode recycle blower provides homogeneous mixing of the three streams mentioned above and minimizes stratification of a single stream.

The cathode feed stream enters the stack at 866 °K. Oxygen and carbon dioxide undergo reduction charge transfer reactions at the gas/electrode/electrolyte interface. The gas leaves the stack at 978 °K.

Cathode feed gas is distributed uniformly to each cell by an inlet manifold. Uniform distribution across the plate surface is achieved by providing channels in the cathode compartment for the gas to flow through. Gas exiting the cell is collected in the outlet manifold.

Recycle Blower

The energy difference between the oxidant/fuel heat-of-reaction and the useful work produced by the MCFC stack is released as heat. This heat must be removed to maintain isothermal operating conditions inside the stack.

Stack cooling is provided to a small extent by gas flow through the anode compartment. However, most of the cooling is provided by the flow of gas through the cathode compartment – approximately twelve times the mass flow of anode gas.

The recycle blower creates the cathode recycle stream, which, when added to air from the compressor and the processed feed stream, provides the gas flow needed to cool the stack.

Inverter

For utility systems, such as this program, the d.c. output from four MCFC fuel cells must be converted to utility-quality a.c. power.

The inverter converts the combined power module fuel cell output voltage of 800-900V dc into 4160 VAC, 3 phase, power for export to the grid, and for use by the plant auxiliaries. The multiple inverter power is collected in a common bus and is joined with the turbine generator power for feed into the step up transformer. The stepup transformer high side bushings are the primary utility interface point.

Gas-Turbine Generator

Cathode-exhaust gas from the thirty-six power modules combines into a single stream which leads to the turbine (expander) section of the gas turbine generator. The high pressure exhaust and heat energy is used to drive the gas turbine compressor section and alternator section. Exhaust gas leaves the turbine section and is ducted to the HRSG. Atmospheric air is compressed in the gas turbine compressor section to approximately 610 kPa. The gas turbine generator system produces 4160VAC for use in plant auxiliaries and the electric utility grid.

HRSG

Waste heat from the turbine exhaust is recovered in the HRSG unit by convective heat transfer. Heat is transferred to preheat natural gas, raise and superheat steam, preheat BFW, and preheat demineralized make-up water. The exhaust gas is discharged to the atmosphere at 446°K.

Design Requirements

A design specification for the plant appears in Table 6.

Table 6
Design Specification

Application	Commercial distributed power generation utility – grid connected.
Fuel	Natural Gas Composition: - Mol% CH_4 96.0 N_2 2.0 CO_2 2.0 S 4 ppmv – mercaptan Supply pressure 15 psig Supply temperature 59°F
Oxidant	Air composition: -Mol% O_2 20.7 N_2 78.0 CO_2 0.3 Water 1.0 (60% relative humidity) Ambient air temperature 59°F Ambient air pressure 14.7 psia
Performance Requirements Power System Design-Point Capacity Design-Point Efficiency Power System Dispatch Mode Power System Normal-Operation Turndown Requirement Power system Overpower Requirement Output Power Conditions Noise Control	20 MW net AC, +/- 2 MW > 70% (net AC/LHV) Base loaded None None 60 Hz, Utility-grid quality Consistent with typical gas turbine power plant practice
Ambient Air Parameter Ranges Pressure Temperature Relative Humidity	 Sea level to 5,000 ft. -20°F to 120°F 0 to 100%

Power System Physical Design Objectives	
Installation	Outdoors
Transportation Options	Truck, sea, air, rail
Transportation Basis	500 miles
Plant Design Lifetime	Conventional power plant equipment – 25 years
Utilities	All utilities needed to support the plant will be available at the site
Power Plant Operation	
Annual Operating Time	Fifty weeks
Annual Planned Shutdown	Two weeks
Instrumentation and Control The I&C system design concept and cost will be based on the projected needs of mature fuel cell/gas turbine technologies and commercial power plant operation	
Economic Evaluation Parameters	
Power system Cost Estimation Basis	Mature technologies and integration techniques, not first-of-a-kind.
Cost Basis	Mid-1998 US Dollars
Fuel Cost	\$3.00/MMBtu (HHV)
Capital Charge Rate	15%
Capacity Factor	92%
COE Evaluation Method	Constant Dollars
Power Plant Optimization Basis	Consistent with >70% (LHV) efficiency, achieve a design-point COE that is 10-20% below the COE achieved by today's conventional-plant technology
Conventional Power Plant Basis - for COE comparison purposes	Comparably sized gas turbine cycle

3.B.2. Plant Performance Summary

3.B.2.a Fuel Cell Stacks

The rated fuel cell performance based on an ambient temperature of 288 °K, relative humidity of 60 percent, sea level elevation, and 101.3 kPa absolute atmospheric pressure at beginning and end of fuel cell life appears below:

Parameter	Beginning of Life	End of Life
Number of Stacks	36	36
Current Density (mA/cm squared)	200	200
Millivolts/Cell	758	700
Power Density (kW/meter squared)	1.52	1.40
kW/Stack	496	458
kW Total from all Stacks	17,856	16,488
Operating Pressure (kPa)	605	605
Fuel Utilization-Per Pass (%)	80.4	80.3
Fuel Utilization-Overall (%)	86.2	86.5

3.B.2.b **Turbine Generator**

The gas turbine generator predicted performance at 288 °K, 101kPa absolute, and sea level conditions for the fuel cell beginning of life and end of life conditions appears below:

Parameter	Beginning of Fuel Cell Life	End of Fuel Cell Life
Compressor		
Compressor Inlet Temperature (°K)	288	288
Compressor Inlet Pressure (kPa)	101	101
Compressor Mass Flow (kg/sec)	16.8	19.2
Compressor Outlet Pressure (kPa)	621	621
Compressor Outlet Temperature (°K)	518	518
Compression Ratio	6.16	6.16
Compressor Efficiency (%)	84	84
Turbine		
Turbine Inlet Temperature (°K)	978	978
Turbine Inlet Pressure (kPa)	594	594
Turbine Mass Flow (kg/sec)	19.1	21.6
Turbine Outlet Pressure (kPa)	105	105
Turbine Outlet Temperature (°K)	671	669
Turbine Efficiency (%)	91.9	91.9
Generator		
Generator Efficiency (%)	98.5	98.5
Power Conditioner		
Power Conditioner Output Voltage (V)	4160	4160
Power Conditioner Output Current (A)	476	530
Power Conditioner Output Power (kW)	3429	3821
Power Conditioner Output Frequency (Hz)	60	60
Power Conditioner Output Phases	3	3
Power Conditioner Efficiency (%)	97.5	97.5

3.B.2.c **Overall Plant**

Plant performance summary tables are provided for the following cases:

Table 7 – Major Subsystem Design Parameters and Operating Conditions. This table represents expected operating conditions for major plant components at SOR and EOR fuel cell conditions for a plant at sea level.

Table 8 – Start of Run (SOR), sea level summary performance table. This table presents performance data for three different ambient air temperatures, at SOR, full-load operation and for a plant site at sea level.

Table 9 – Start of Run (SOR), 5,000 ft elevation summary performance table. This table presents performance data for three different ambient air temperatures, at SOR, full-load operation and for a plant site at 5,000 ft elevation.

Table 10 – End of Run (EOR), sea level summary performance table. This table presents performance data for two ambient air temperatures, at EOR, full-load operation and for a plant site at sea level.

TABLE 7
Major Subsystem
Design Parameters and Operating Conditions
Site Elevation – Sea Level

	Start of Run ~~SOR~~	End of Run ~~EOR~~
Fuel Processor - Reformer	Type: External/Separate - IHI Gas-Heated Plate-Type	
Steam:Hydrocarbon ratio	4.68	5.3
Steam:Total Carbon ratio	1.43	1.5
Operating Pressure, kPa	606	606
Exit Temperature, K	1,061	1,061
Process Duty, kJ/h	1,018,806	1,026,361
Number of Units	36	36
Fuel Cell Stack Design	Type: MC-Power Molten Carbonate, Co-Flow	
Operating Pressure, kPa	605	605
Current Density, mA/cm2	200	200
Cell Voltage, mV	758	700
Power Density, kW/m2	1.52	1.40
Fuel Utilization - per pass, %	80.4	80.3
Fuel Utilization - overall, %	86.2	86.5
Number of Stacks Required	36	36
Inverter Design	Type: Solid-State	
Input Voltage, Volts	227	210
Input Current, Amps DC	2,180	2,180
Output Voltage, Volts	4,160	4,160
Output Electric Power, kW	479	443
Power Conversion Efficiency, %	97.5	97.5
Number of Units Required	9	9
Recycle Gas Blower		
Adiabatic Efficiency, %	75	75
Differential Pressure, kPa	6.2	6.2
Shaft Horse Power, kW	108	119
Motor Efficiency, %	92	92
Number of Units	3	3
Gas Turbine Design	Type: Rolls-Royce Allison	
Compression Ratio	6.16	6.16
Compressor Air Flow, kg/s	16.81	19.19
Compressor Efficiency, %	84	84
Turbine Efficiency, %	91.9	91.9
Generator Efficiency, %	98.5	98.5
Net Power Production, kW	20,115	19,159
Overall Electrical Efficiency	70.11	66.78

TABLE 8
Performance Summary
Site Elevation – Sea Level

~~**Start-of-Run Operation**~~

Ambient Temperature, °K	288	244	322	322
Relative Humidity	60%	0%	0%	100%
AC Power from Power Modules, kW	17,256	17,256	17,256	17,256
AC Power from Gas turbine Generator, kW	~~3,429~~	~~3,603~~	~~3,246~~	~~3,242~~
Gross Power Production, kW	**20,685**	**20,859**	**20,502**	**20,498**
Auxiliary Loads, kW	570	571	571	563
Net Power Production, kW	**20,115**	**20,288**	**19,931**	**19,935**
Natural Gas Consumption, kJ/h (LHV)	1.0328E+08	1.0328E+08	1.0328E+08	1.0328E+08
Fuel Fired in Gas Turbine, kJ/h (LHV)	0	0	0	0
Fuel Fired in HRSG, kJ/h (LHV)	0	0	0	0
Overall Electrical Efficiency (LHV), %	**70.11**	**70.72**	**69.47**	**69.49**

TABLE 9
Performance Summary
Site Elevation – 5,000’

~~Start-of-Run Operation~~				
Ambient Temperature, °K	288	244	322	322
Relative Humidity	60%	0%	0%	100%
AC Power from Power Modules, kW	17,256	17,256	17,256	17,256
AC Power from Gas turbine Generator, kW	~~3,099~~	~~3,368~~	~~2,819~~	~~2,845~~
Gross Power Production, kW	**20,355**	**20,624**	**20,075**	**20,101**
Auxiliary Loads, kW	570	571	571	563
Net Power Production, kW	**19,785**	**20,052**	**19,504**	**19,538**
Natural Gas Consumption, kJ/h (LHV)	1.0328E+08	1.0328E+08	1.0328E+08	1.0328E+08
Fuel Fired in Gas Turbine, kJ/h (LHV)	0	0	0	0
Fuel Fired in HRSG, kJ/h (LHV)	0	0	0	0
Overall Electrical Efficiency (LHV), %	**68.96**	**69.90**	**67.98**	**68.10**

TABLE 10
Performance Summary
Site Elevation – Sea Level

~~**End-of-Run Operation**~~		
Ambient Temperature, °K	288	322
Relative Humidity	60%	0%
AC Power from Power Modules, kW	15,946	15,946
AC Power from Gas turbine Generator, kW	~~3,821~~	~~3,595~~
Gross Power Production, kW	**19,767**	**19,541**
Auxiliary Loads, kW	608	610
Net Power Production, kW	**19,159**	**18,931**
Natural Gas Consumption, kJ/h (LHV)	1.0328E+08	1.0328E+08
Fuel Fired in Gas Turbine, kJ/h (LHV)	0	0
Fuel Fired in HRSG, kJ/h (LHV)	0	0
Overall Electrical Efficiency (LHV), %	**66.78**	**65.99**

3.B.3. Process Flow Diagram

Start-of-Run (SOR) Operation

DWG B-001 is the process flow diagram (PFD) for the HEFPP overall facility. It depicts the design and control concepts, process equipment, and presents the flows and conditions for all streams entering and exiting the facility, including electric power.

DWG B-002 is the process flow diagram (PFD) for a single power module. It depicts the design and control concepts, process equipment, and presents the flows and conditions for all streams entering and exiting a single power module contained within a power-module vessel.

Operating conditions shown on these drawings are for full-load, SOR operation at 15°C ambient air temperature and at sea level.

The process stream flows and conditions for the following other operating cases are shown on the PFDs.

DRAWING B-001

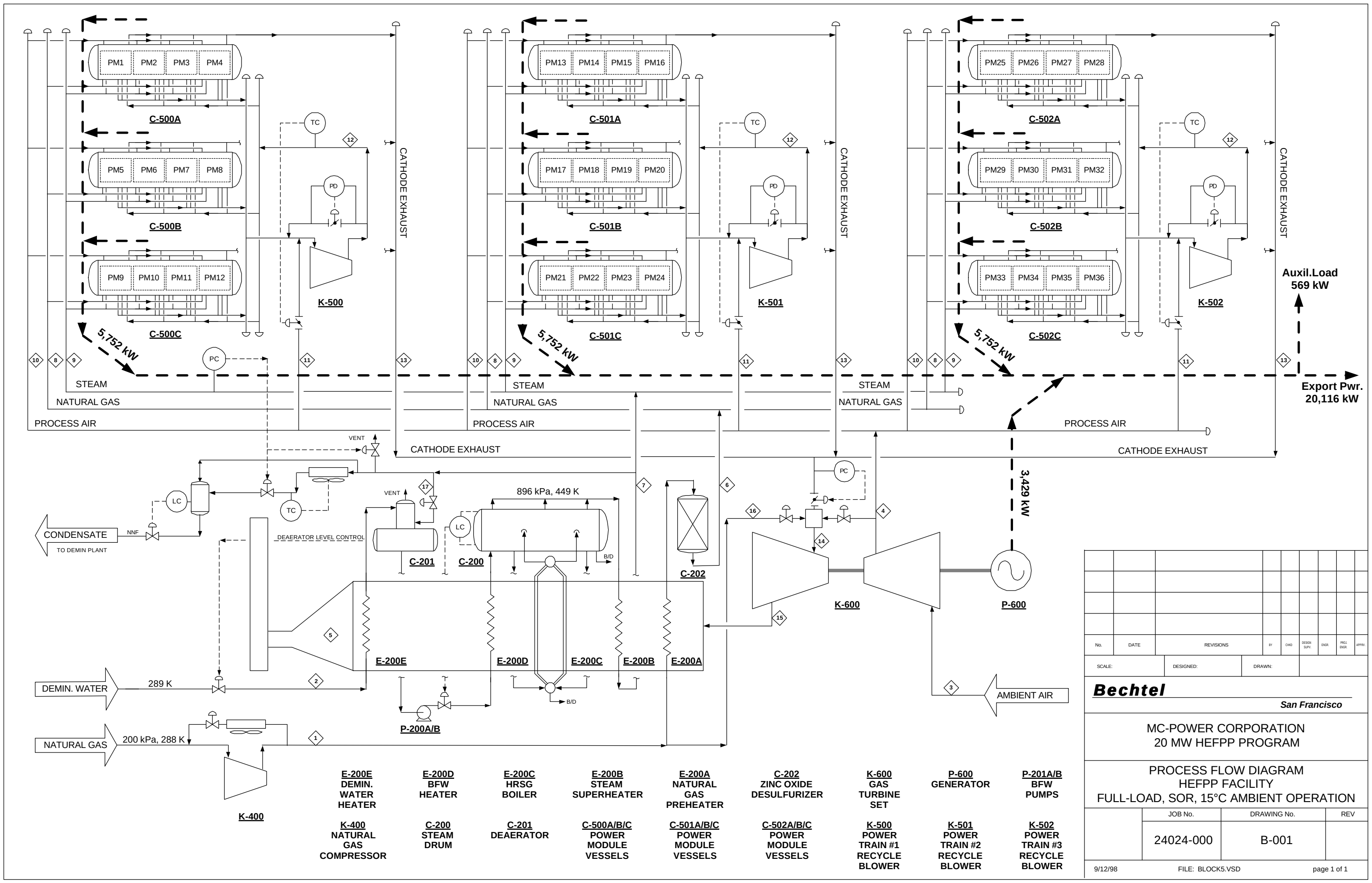


TABLE 11
Material Balance – Full-Load, SOR – Sea Level 15°C/-29°C Ambient Air (Page 1 of 2)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	288	518	446	616	536	616	536	518	518	866	978	978	671	426	536
Pressure, kPa	749	276	101	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	5,933	60,507	60,507	68,688	2,257	6,124	752	1,975	341	19,828	105,577	22,896	68,688	68,688	-	200
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	3,004	-	47,113	47,113	57,487	3,004	7,619	1,001	2,457	266	15,439	85,949	19,162	57,487	57,487	-	248
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	6.31	6.31	137.66	2.68	-	0.89	-	0.04	2.07	339.41	45.89	137.66	137.66	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	329.36	21.02	21.02	607.22	-	339.93	-	109.62	0.12	6.89	856.26	202.41	607.22	607.22	-	11.08
N2	2.68	-	1,639.52	1,639.52	1,642.17	2.68	-	0.89	-	9.25	537.26	2,315.66	547.39	1,642.17	1,642.17	-	-
O2	-	-	435.10	435.10	177.75	-	-	-	-	2.45	142.58	323.29	59.25	177.75	177.75	-	-
Total, kg-mole/hr	134.04	329.36	2,101.94	2,101.94	2,564.80	134.04	339.93	44.68	109.62	11.86	688.79	3,834.63	854.93	2,564.80	2,564.80	-	11.08
Density, kg/m3	3.58	1,014.84	1.21	4.14	0.73	2.35	3.69	2.35	3.67	4.11	4.11	2.31	1.98	1.95	0.50	3.58	3.69
Mole Wt.	16.84	18.02	28.79	28.79	26.78	16.84	18.02	16.84	18.02	28.79	28.79	27.53	26.78	26.78	26.78	16.84	18.02
Z Factor	0.996	-	0.999	1.002	0.999	1.001	0.972	1.001	0.972	1.002	1.002	1.001	1.001	1.001	1.000	0.996	0.972

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -29°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	244	441	450	616	536	616	536	441	441	866	978	978	671	426	536
Pressure, kPa	749	276	101	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	5,190	53,802	53,802	61,239	2,257	5,356	752	1,727	343	17,591	106,199	20,413	61,239	61,239	-	175
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	3,004	-	41,734	41,734	51,184	3,004	6,663	1,001	2,149	266	13,646	86,359	17,061	51,184	51,184	-	217
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	5.64	5.64	137.00	2.68	-	0.89	-	0.04	1.84	363.37	45.67	137.00	137.00	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	288.08	-	-	544.93	-	297.28	-	95.86	-	-	867.42	181.64	544.93	544.93	-	9.70
N2	2.68	-	1,467.00	1,467.00	1,469.68	2.68	-	0.89	-	9.34	479.66	2,339.41	489.89	1,469.68	1,469.68	-	-
O2	-	-	389.32	389.32	131.97	-	-	-	-	2.48	127.29	282.71	43.99	131.97	131.97	-	-
Total, kg-mole/hr	134.04	288.08	1,861.96	1,861.96	2,283.58	134.04	297.28	44.68	95.86	11.86	608.80	3,852.91	761.19	2,283.58	2,283.58	-	9.70
Density, kg/m3	3.58	1,014.84	1.43	4.88	0.73	2.35	3.69	2.35	3.67	4.84	4.84	2.31	1.99	1.96	0.50	3.58	3.69
Mole Wt.	16.84	18.02	28.90	28.90	26.82	16.84	18.02	16.84	18.02	28.90	28.90	27.56	26.82	26.82	26.82	16.84	18.02
Z Factor	0.996	-	0.999	1.001	0.999	1.001	0.972	1.001	0.972	1.001	1.001	1.001	1.001	1.001	1.000	0.996	0.972

MATERIAL BALANCE - HEFPP FACILITY	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000 DOCUMENT NO. SHEET 1 OF 2	REV.

TABLE 11 cont.
Material Balance - Full Load, SOR – Sea Level 49°C (0% /100% Rel. Humity) (Page 2 of 2)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	322	577	449	616	536	616	536	577	577	866	978	978	669	426	536
Pressure, kPa	749	276	101	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	6,465	68,293	68,293	77,006	2,257	6,673	752	2,152	343	22,422	106,497	25,669	77,006	77,006	-	217
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	3,004	-	52,975	52,975	64,012	3,004	8,302	1,001	2,677	266	17,393	86,163	21,337	64,012	64,012	-	270
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	7.16	7.16	138.52	2.68	-	0.89	-	0.04	2.35	321.18	46.17	138.52	138.52	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	358.85	-	-	615.68	-	370.40	-	119.45	-	-	781.75	205.23	615.68	615.68	-	12.06
N2	2.68	-	1,862.13	1,862.13	1,864.84	2.68	-	0.89	-	9.34	611.37	2,367.87	621.61	1,864.84	1,864.84	-	-
O2	-	-	494.18	494.18	236.83	-	-	-	-	2.48	162.25	373.36	78.94	236.83	236.83	-	-
Total, kg-mole/hr	134.04	358.85	2,363.47	2,363.47	2,855.88	134.04	370.40	44.68	119.45	11.86	775.97	3,844.17	951.96	2,855.88	2,855.88	-	12.06
Density, kg/m3	3.58	1,014.84	1.09	3.73	0.73	2.35	3.69	2.35	3.67	3.70	3.70	2.32	2.00	1.97	0.51	3.58	3.69
Mole Wt.	16.84	18.02	28.90	28.90	26.96	16.84	18.02	16.84	18.02	28.90	28.90	27.70	26.96	26.96	26.96	16.84	18.02
Z Factor	0.996	-	1.000	1.002	0.999	1.001	0.972	1.001	0.972	1.002	1.002	1.001	1.001	1.001	1.000	0.996	0.972

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	322	571	449	616	536	616	536	571	571	866	978	978	674	426	536
Pressure, kPa	749	276	101	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	6,546	62,585	62,585	71,379	2,257	6,757	752	2,179	328	20,534	100,244	23,793	71,379	71,379	-	220
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	3,004	-	50,748	50,748	61,886	3,004	8,407	1,001	2,711	266	16,650	84,238	20,629	61,886	61,886	-	274
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	6.07	6.07	137.43	2.68	-	0.89	-	0.03	1.99	321.51	45.81	137.43	137.43	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	363.38	260.81	260.81	881.05	-	375.09	-	120.96	1.37	85.57	1,129.70	293.68	881.05	881.05	-	12.21
N2	2.68	-	1,578.38	1,578.38	1,581.06	2.68	-	0.89	-	8.27	517.86	2,027.29	527.02	1,581.06	1,581.06	-	-
O2	-	-	418.88	418.88	161.52	-	-	-	-	2.19	137.43	279.76	53.84	161.52	161.52	-	-
Total, kg-mole/hr	134.04	363.38	2,264.14	2,264.14	2,761.06	134.04	375.09	44.68	120.96	11.86	742.86	3,758.26	920.35	2,761.06	2,761.06	-	12.21
Density, kg/m3	3.58	1,014.84	1.04	3.61	0.70	2.35	3.69	2.35	3.67	3.58	3.58	2.24	1.91	1.89	0.48	3.58	3.69
Mole Wt.	16.84	18.02	27.64	27.64	25.85	16.84	18.02	16.84	18.02	27.64	27.64	26.67	25.85	25.85	25.85	16.84	18.02
Z Factor	0.996	-	0.999	1.001	0.999	1.001	0.972	1.001	0.972	1.001	1.001	1.001	1.001	1.001	1.000	0.996	0.972

			JOB NO.: 24024-000
BECHTEL	MATERIAL BALANCE - HEFPP FACILITY	MC-POWER CORPORATION	DOCUMENT NO. / REV.
		20 MW HEFPP PROGRAM	
			SHEET 2 OF 2

TABLE 12
Material Balance – Full Load SOR – 5,000’ Elev./15°C/-29°C Ambient Air (Page 1 of 2)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	288	543	447	616	536	616	536	543	543	867	978	978	670	426	536
Pressure, kPa	749	276	86	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	6,146	63,408	63,408	71,803	2,257	6,343	752	2,046	341	20,795	105,767	23,934	71,803	71,803	-	207
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	3,004	-	49,372	49,372	60,011	3,004	7,892	1,001	2,545	266	16,192	85,996	20,004	60,011	60,011	-	257
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	6.61	6.61	137.96	2.68	-	0.89	-	0.04	2.17	331.76	45.99	137.96	137.96	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	341.15	22.03	22.03	619.98	-	352.12	-	113.55	0.12	7.22	837.96	206.66	619.98	619.98	-	11.47
N2	2.68	-	1,718.13	1,718.13	1,720.83	2.68	-	0.89	-	9.25	563.46	2,325.86	573.61	1,720.83	1,720.83	-	-
O2	-	-	455.96	455.96	198.63	-	-	-	-	2.45	149.53	341.12	66.21	198.63	198.63	-	-
Total, kg-mole/hr	134.04	341.15	2,202.73	2,202.73	2,677.41	134.04	352.12	44.68	113.55	11.86	722.39	3,836.70	892.47	2,677.41	2,677.41	-	11.47
Density, kg/m3	3.58	1,014.84	1.04	3.95	0.73	2.35	3.69	2.35	3.67	3.92	3.92	2.31	1.99	1.96	0.50	3.58	3.69
Mole Wt.	16.84	18.02	28.79	28.79	26.82	16.84	18.02	16.84	18.02	28.79	28.79	27.57	26.82	26.82	26.82	16.84	18.02
Z Factor	0.996	-	0.999	1.002	0.999	1.001	0.972	1.001	0.972	1.002	1.002	1.001	1.001	1.001	1.000	0.996	0.972

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -29°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	244	463	449	616	536	616	536	463	463	866	978	978	671	426	536
Pressure, kPa	749	276	86	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	5,361	55,659	55,659	63,269	2,257	5,533	752	1,784	343	18,210	106,273	21,090	63,269	63,269	-	181
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	3,004	-	43,175	43,175	52,838	3,004	6,884	1,001	2,220	266	14,126	86,357	17,613	52,838	52,838	-	225
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	5.84	5.84	137.19	2.68	-	0.89	-	0.04	1.91	356.83	45.73	137.19	137.19	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	297.61	-	-	554.45	-	307.13	-	99.04	-	-	854.91	184.82	554.45	554.45	-	10.02
N2	2.68	-	1,517.65	1,517.65	1,520.33	2.68	-	0.89	-	9.34	496.54	2,344.20	506.78	1,520.33	1,520.33	-	-
O2	-	-	402.76	402.76	145.41	-	-	-	-	2.48	131.77	296.86	48.47	145.41	145.41	-	-
Total, kg-mole/hr	134.04	297.61	1,926.24	1,926.24	2,357.39	134.04	307.13	44.68	99.04	11.86	630.23	3,852.79	785.80	2,357.39	2,357.39	-	10.02
Density, kg/m3	3.58	1,014.84	1.23	4.65	0.73	2.35	3.69	2.35	3.67	4.61	4.61	2.31	1.99	1.96	0.50	3.58	3.69
Mole Wt.	16.84	18.02	28.90	28.90	26.84	16.84	18.02	16.84	18.02	28.90	28.90	27.58	26.84	26.84	26.84	16.84	18.02
Z Factor	0.996	-	0.999	1.001	0.999	1.001	0.972	1.001	0.972	1.001	1.001	1.001	1.001	1.001	1.000	0.996	0.972

MATERIAL BALANCE - HEFPP FACILITY	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000 DOCUMENT NO. SHEET 1 OF 2	REV.

TABLE 12
Material Balance – Full Load SOR – 5,000’ Elev./49°(0%/100% Rel. Humidity) (Page 2 of 2)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	322	605	450	616	536	616	536	605	605	866	978	978	668	426	536
Pressure, kPa	749	276	86	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	6,791	72,373	72,373	81,410	2,257	7,011	752	2,261	343	23,782	106,589	27,137	81,410	81,410	-	228
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	3,004	-	56,140	56,140	67,581	3,004	8,722	1,001	2,813	266	18,447	86,130	22,527	67,581	67,581	-	284
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	7.59	7.59	138.95	2.68	-	0.89	-	0.04	2.49	312.34	46.32	138.95	138.95	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	376.99	-	-	633.85	-	389.15	-	125.50	-	-	762.01	211.28	633.85	633.85	-	12.66
N2	2.68	-	1,973.38	1,973.38	1,975.98	2.68	-	0.89	-	9.34	648.45	2,375.51	658.66	1,975.98	1,975.98	-	-
O2	-	-	523.70	523.70	266.33	-	-	-	-	2.48	172.09	392.82	88.78	266.33	266.33	-	-
Total, kg-mole/hr	134.04	376.99	2,504.67	2,504.67	3,015.11	134.04	389.15	44.68	125.50	11.86	823.03	3,842.67	1,005.04	3,015.11	3,015.11	-	12.66
Density, kg/m3	3.58	1,014.84	0.93	3.56	0.73	2.35	3.69	2.35	3.67	3.53	3.53	2.33	2.00	1.97	0.51	3.58	3.69
Mole Wt.	16.84	18.02	28.90	28.90	27.00	16.84	18.02	16.84	18.02	28.90	28.90	27.74	27.00	27.00	27.00	16.84	18.02
Z Factor	0.996	-	1.000	1.002	0.999	1.001	0.972	1.001	0.972	1.002	1.002	1.001	1.001	1.001	1.000	0.996	0.972

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	322	598	448	616	536	616	536	598	598	866	978	978	674	426	536
Pressure, kPa	749	276	86	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	6,914	66,028	66,028	75,191	2,257	7,137	752	2,302	328	21,682	100,225	25,064	75,191	75,191	-	232
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	3,004	-	53,541	53,541	65,136	3,004	8,880	1,001	2,864	266	17,581	84,155	21,712	65,136	65,136	-	289
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	128.68	-	-	-	-	128.68	-	42.89	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	2.68	-	6.40	6.40	137.77	2.68	-	0.89	-	0.03	2.10	312.96	45.92	137.77	137.77	-	-
H2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2O	-	383.79	275.16	275.16	915.80	-	396.18	-	127.76	1.37	90.35	1,114.51	305.27	915.80	915.80	-	12.89
N2	2.68	-	1,665.22	1,665.22	1,667.91	2.68	-	0.89	-	8.27	546.81	2,029.82	555.97	1,667.91	1,667.91	-	-
O2	-	-	441.92	441.92	184.57	-	-	-	-	2.19	145.11	297.26	61.52	184.57	184.57	-	-
Total, kg-mole/hr	134.04	383.79	2,388.71	2,388.71	2,906.04	134.04	396.18	44.68	127.76	11.86	784.38	3,754.55	968.68	2,906.04	2,906.04	-	12.89
Density, kg/m3	3.58	1,014.84	0.89	3.45	0.70	2.35	3.69	2.35	3.67	3.42	3.42	2.24	1.92	1.89	0.48	3.58	3.69
Mole Wt.	16.84	18.02	27.64	27.64	25.87	16.84	18.02	16.84	18.02	27.64	27.64	26.69	25.87	25.87	25.87	16.84	18.02
Z Factor	0.996	-	0.999	1.001	0.999	1.001	0.972	1.001	0.972	1.001	1.001	1.001	1.001	1.001	1.000	0.996	0.972

BECHTEL	MATERIAL BALANCE - HEFPP FACILITY	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000 DOCUMENT NO. / REV. SHEET 2 OF 2

TABLE 13
Material Balance – Full Load EOR – Sea Level 15°C/49°C (0% Rel. Humidity) Ambient Air

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	288	518	449	616	536	616	536	518	518	866	978	978	669	426	536
Pressure, kPa	749	276	101	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	6,587	69,074	69,074	77,909	2,257	6,799	752	2,193	341	22,683	117,055	25,970	77,909	77,909	-	221
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	3,004		53,783	53,783	64,972	3,004	8,460	1,001	2,728	266	17,662	95,232	21,657	64,972	64,972	-	275
Molar Flow, kg-mole/hr																	
CH_4	128.68	-	-	-	-	128.68	-	42.89						-	-	-	
CO	-	-	-	-	-	-	-							-	-	-	
CO_2	2.68	-	7.20	7.20	138.57	2.68	-	0.89		0.04	2.36	337.98	46.19	138.57	138.57	-	
H_2	-	-	-	-	-	-	-							-	-	-	
H_2O	-	365.65	24.00	24.00	646.52	-	377.43		121.72	0.12	7.88	899.03	215.51	646.52	646.52	-	12.28
N_2	2.68	-	1,871.63	1,871.63	1,874.29	2.68	-	0.89		9.25	614.63	2,606.32	624.76	1,874.29	1,874.29	-	
O_2	-	-	496.70	496.70	239.33	-	-			2.45	163.11	405.44	79.78	239.33	239.33	-	
Total, kg-mole/hr	134.04	365.65	2,399.53	2,399.53	2,898.71	134.04	377.43	44.68	121.72	11.86	787.99	4,248.77	966.24	2,898.71	2,898.71	-	12.28
Density, kg/m3	3.58	1,014.84	1.21	4.14	0.73	2.35	3.69	2.35	3.67	4.11	4.11	2.31	1.99	1.96	0.51	3.58	3.69
Mole Wt.	16.84	18.02	28.79	28.79	26.88	16.84	18.02	16.84	18.02	28.79	28.79	27.55	26.88	26.88	26.88	16.84	18.02
Z Factor	0.996		0.999	1.002	0.999	1.001	0.972	1.001	0.972	1.002	1.002	1.001	1.001	1.001	1.000	0.996	0.972

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stream Description:	Total Natural Gas Feed	Demin. Feedwater	Total Air Feed	Process Air	Flue Gas Vent to Atmosphere	Desulfurized Natural Gas	Superheated Steam	Nat. Gas to Power Train	Sht'd. Steam to Power Train	Process Air to Power Train	Process Air to Power Train	Recycle Blower Discharge	Cathode Exhaust from Power Train	Turbine Inlet	Turbine Exhaust	Turbine Nat. Gas Fuel	Steam to Dearator
Temperature, K	426	289	322	577	456	616	536	616	536	577	577	866	978	978	667	426	536
Pressure, kPa	749	276	101	621	101.4	715	886	715	881	616	616	605	603	594	105	749	886
Mass Flow, kg/h	2,257	7,035	78,300	78,300	87,582	2,257	7,262	752	2,342	343	25,757	118,310	29,194	87,582	87,582	-	236
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	3,004		60,737	60,737	72,483	3,004	9,035	1,001	2,914	266	19,980	95,582	24,161	72,483	72,483	-	294
Molar Flow, kg-mole/hr																	
CH_4	128.68	-	-	-	-	128.68	-	42.89						-	-	-	
CO	-	-	-	-	-	-	-							-	-	-	
CO_2	2.68	-	8.21	8.21	139.57	2.68	-	0.89		0.04	2.70	319.94	46.52	139.57	139.57	-	
H_2	-	-	-	-	-	-	-							-	-	-	
H_2O	-	390.50	-	-	647.35	-	403.11		130.00	-	-	810.02	215.78	647.35	647.35	-	13.11
N_2	2.68	-	2,134.98	2,134.98	2,137.66	2.68	-	0.89		9.34	702.32	2,674.82	712.55	2,137.66	2,137.66	-	
O_2	-	-	566.59	566.59	309.24	-	-			2.48	186.38	459.59	103.08	309.24	309.24	-	
Total, kg-mole/hr	134.04	390.50	2,709.78	2,709.78	3,233.82	134.04	403.11	44.68	130.00	11.86	891.41	4,264.37	1,077.94	3,233.82	3,233.82	-	13.11
Density, kg/m3	3.58	1,014.84	1.09	3.73	0.72	2.35	3.69	2.35	3.67	3.70	3.70	2.33	2.01	1.98	0.51	3.58	3.69
Mole Wt.	16.84	18.02	28.90	28.90	27.08	16.84	18.02	16.84	18.02	28.90	28.90	27.74	27.08	27.08	27.08	16.84	18.02
Z Factor	0.996		1.000	1.002	1.000	1.001	0.972	1.001	0.972	1.002	1.002	1.001	1.001	1.001	1.000	0.996	0.972

BECHTEL	MATERIAL BALANCE - HEFPP FACILITY	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000 DOCUMENT NO. REV. SHEET 1 OF 2

DRAWING B-002

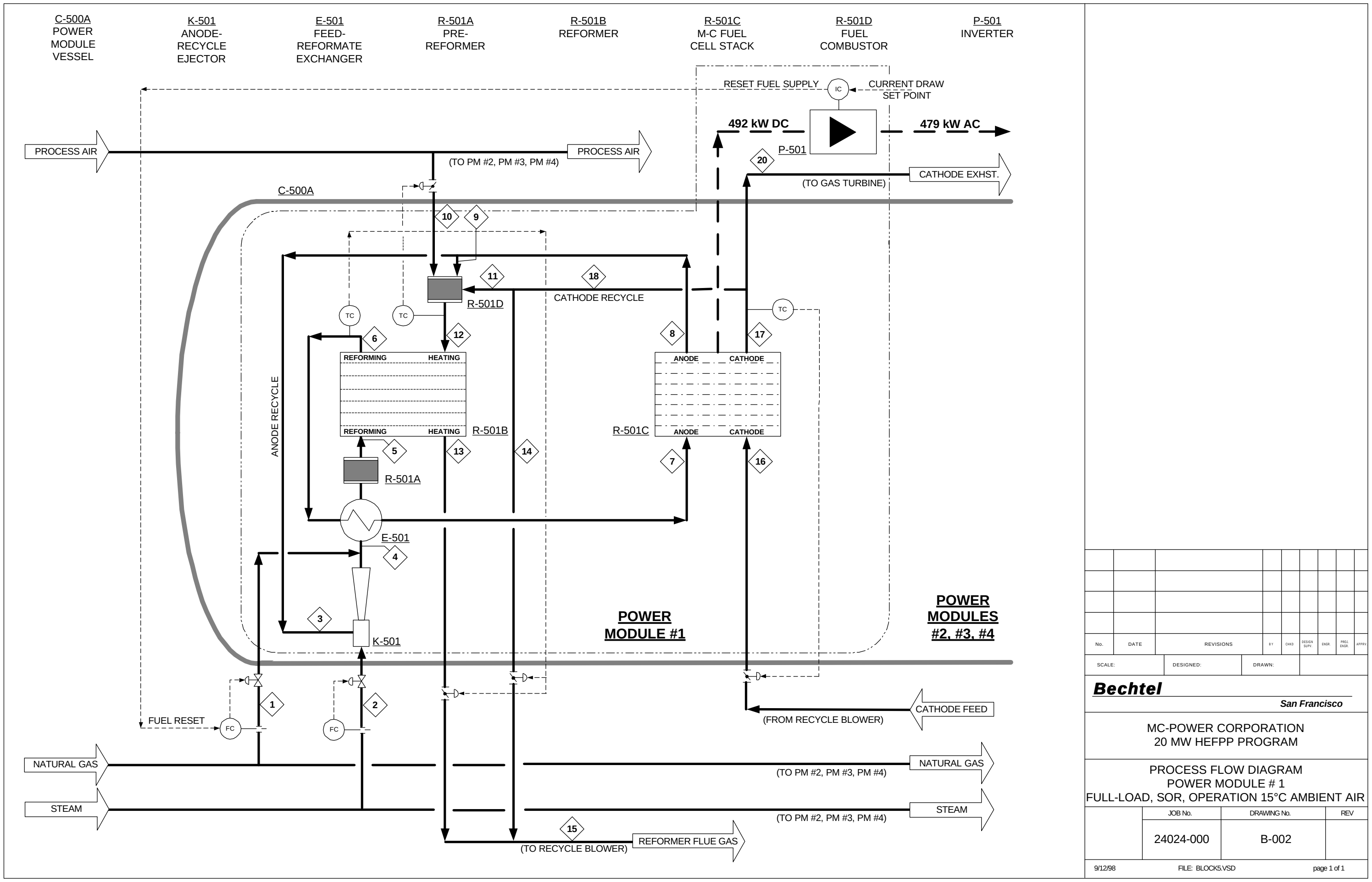


TABLE 14
Material Balance – Full Load SOR – Sea Level/15°C/-29°C Ambient Air (Page 1 of 2)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	801	799	1,061	950	978	978	518	978	1,072	893	978	929	866	978	978	978
Pressure, kPa	698	872	604.1	609.3	608.6	606.3	604.8	604.4	604.1	602.5	602.5	601.9	600.7	602.5	598.6	603.8	603.0	602.5	602.5
Mass Flow, kg/h	63	165	494	721	721	721	721	1,448	954	28	3,114	4,096	4,096	3,050	7,146	8,798	8,072	6,164	1,908
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	83	205	371	659	698	817	817	1,088	717	22	2,606	3,323	3,323	2,553	5,876	7,162	6,755	5,158	1,597
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.03	3.61	2.75	0.10	0.10	0.10	0.06	-	-	-	-	-	-	1.45	-	-	-
CO	-	-	0.40	0.40	0.54	4.71	4.71	1.17	0.77	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	7.72	7.80	8.52	7.00	7.00	22.64	14.92	0.00	6.24	22.00	22.00	6.11	28.11	28.28	16.18	12.35	3.82
H2	-	-	0.60	0.60	3.90	10.34	10.34	1.77	1.16	-	-	-	-	-	-	-	-	-	-
H2O	-	9.13	7.76	16.90	15.32	14.19	14.19	22.75	14.99	0.01	27.53	43.82	43.82	26.96	70.78	71.36	71.36	54.49	16.87
N2	0.07	-	0.04	0.11	0.11	0.11	0.11	0.11	0.07	0.77	74.44	75.29	75.29	72.91	148.20	192.97	192.97	147.36	45.62
O2	-	-	-	-	-	-	-	-	-	0.20	8.06	7.17	7.17	7.89	15.06	26.94	20.89	15.95	4.94
Total, kg-mole/hr	3.72	9.13	16.56	29.42	31.13	36.44	36.44	48.55	31.99	0.99	116.26	148.27	148.27	113.88	262.15	319.55	301.39	230.15	71.24
Density, kg/m3	2.29	3.63	2.22	2.25	2.12	1.36	1.51	2.22	2.22	4.02	1.98	1.86	2.23	1.98	2.11	2.30	1.98	1.98	1.98
Mole Wt.	16.84	18.02	29.82	24.51	23.16	19.79	19.79	29.82	29.82	28.79	26.78	27.62	27.62	26.78	27.26	27.53	26.78	26.78	26.78
Z Factor	1.001	-	1.000	0.999	0.999	1.001	1.001	1.000	1.000	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -29°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	811	804	1,061	950	978	978	441	978	1,072	894	978	931	866	978	978	978
Pressure, kPa	698	872	604.1	609.2	608.5	606.3	604.8	604.4	604.1	602.5	602.5	601.9	600.7	602.5	598.6	603.8	603.0	602.5	602.5
Mass Flow, kg/h	63	144	504	710	710	710	710	1,437	933	29	3,122	4,083	4,083	3,301	7,384	8,850	8,123	6,422	1,701
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	83	179	373	635	674	793	793	1,064	691	22	2,609	3,301	3,301	2,759	6,059	7,197	6,790	5,368	1,422
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.04	3.61	2.76	0.11	0.11	0.11	0.07	-	-	-	-	-	-	4.16	-	-	-
CO	-	-	0.43	0.43	0.62	5.01	5.01	1.23	0.80	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	8.04	8.11	8.77	7.04	7.04	22.93	14.89	0.00	6.98	22.74	22.74	7.38	30.13	30.28	18.17	14.37	3.81
H2	-	-	0.60	0.60	3.82	10.04	10.04	1.72	1.11	-	-	-	-	-	-	-	-	-	-
H2O	-	7.99	7.49	15.48	13.97	13.05	13.05	21.38	13.88	-	27.78	42.92	42.92	29.37	72.28	72.28	72.28	57.15	15.14
N2	0.07	-	0.04	0.11	0.11	0.11	0.11	0.11	0.07	0.78	74.92	75.77	75.77	79.21	154.98	194.95	194.95	154.13	40.82
O2	-	-	-	-	-	-	-	-	-	0.21	6.73	5.84	5.84	7.11	12.95	23.56	17.51	13.84	3.67
Total, kg-mole/hr	3.72	7.99	16.64	28.35	30.05	35.36	35.36	47.47	30.83	0.99	116.41	147.27	147.27	123.08	270.34	321.08	302.91	239.48	63.43
Density, kg/m3	2.29	3.63	2.25	2.27	2.15	1.38	1.54	2.25	2.25	4.74	1.99	1.87	2.24	1.99	2.11	2.31	1.99	1.99	1.99
Mole Wt.	16.84	18.02	30.27	25.05	23.63	20.09	20.09	30.27	30.27	28.90	26.82	27.73	27.73	26.82	27.31	27.56	26.82	26.82	26.82
Z Factor	1.001	-	1.000	0.999	0.999	1.001	1.001	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

BECHTEL	MATERIAL BALANCE - POWER MODULE #1	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000 DOCUMENT NO. REV. SHEET 1 OF 2

TABLE 14
Material Balance – Full Load SOR – Sea Level/49°C (0%/100% Rel. Humidity) Ambient Air (Page 2 of 2)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	804	801	1,061	950	978	978	577	978	1,072	892	978	926	866	978	978	978
Pressure, kPa	698	872	604.2	610.3	609.4	606.8	605.0	604.6	604.2	602.5	602.5	602.0	600.7	602.5	598.6	603.8	603.0	602.5	602.5
Mass Flow, kg/h	63	179	538	780	780	780	780	1,507	969	29	3,165	4,163	4,163	2,844	7,006	8,875	8,148	6,009	2,139
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	83	223	409	715	757	873	873	1,145	736	22	2,631	3,367	3,367	2,364	5,731	7,180	6,773	4,995	1,778
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.03	3.60	2.67	0.08	0.08	0.08	0.05	-	-	-	-	-	-	-	-	-	-
CO	-	-	0.43	0.43	0.58	4.68	4.68	1.20	0.77	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	8.30	8.37	9.15	7.65	7.65	23.23	14.94	0.00	5.69	21.45	21.45	5.12	26.57	26.77	14.66	10.81	3.85
H2	-	-	0.68	0.68	4.25	10.53	10.53	1.90	1.22	-	-	-	-	-	-	-	-	-	-
H2O	-	9.95	8.77	18.72	17.01	15.92	15.92	24.55	15.78	-	25.31	42.41	42.41	22.74	65.15	65.15	65.15	48.04	17.10
N2	0.07	-	0.04	0.12	0.12	0.12	0.12	0.12	0.07	0.78	76.66	77.51	77.51	68.86	146.37	197.32	197.32	145.52	51.80
O2	-	-	-	-	-	-	-	-	-	0.21	9.74	8.85	8.85	8.75	17.59	31.11	25.06	18.48	6.58
Total, kg-mole/hr	3.72	9.95	18.24	31.91	33.78	38.96	38.96	51.07	32.83	0.99	117.40	150.22	150.22	105.46	255.68	320.35	302.19	222.86	79.33
Density, kg/m3	2.29	3.63	2.19	2.23	2.12	1.38	1.53	2.19	2.19	3.62	2.00	1.87	2.24	2.00	2.13	2.32	2.00	2.00	2.00
Mole Wt.	16.84	18.02	29.50	24.44	23.09	20.02	20.02	29.50	29.50	28.90	26.96	27.71	27.71	26.96	27.40	27.70	26.96	26.96	26.96
Z Factor	1.001	-	1.000	0.998	0.999	1.001	1.000	1.000	1.000	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	804	801	1,061	950	978	978	571	978	1,072	892	978	926	866	978	978	978
Pressure, kPa	698	872	603.6	609.9	609.0	606.3	604.4	604.0	603.6	602.5	602.5	601.6	600.4	602.5	598.5	603.7	603.0	602.5	602.5
Mass Flow, kg/h	63	182	545	789	789	789	789	1,516	971	27	2,956	3,954	3,954	2,688	6,642	8,354	7,627	5,644	1,983
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	83	226	415	724	766	882	882	1,153	739	22	2,563	3,302	3,302	2,331	5,632	7,020	6,613	4,894	1,719
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.03	3.60	2.66	0.08	0.08	0.08	0.05	-	-	-	-	-	-	-	-	-	-
CO	-	-	0.43	0.43	0.58	4.67	4.67	1.20	0.77	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	8.38	8.46	9.25	7.75	7.75	23.32	14.94	0.00	5.69	21.45	21.45	5.18	26.63	26.79	14.68	10.87	3.82
H2	-	-	0.69	0.69	4.30	10.56	10.56	1.92	1.23	-	-	-	-	-	-	-	-	-	-
H2O	-	10.08	8.92	19.00	17.27	16.19	16.19	24.83	15.91	0.11	36.49	53.83	53.83	33.18	87.01	94.14	94.14	69.67	24.47
N2	0.07	-	0.04	0.12	0.12	0.12	0.12	0.12	0.07	0.69	65.48	66.24	66.24	59.54	125.79	168.94	168.94	125.02	43.92
O2	-	-	-	-	-	-	-	-	-	0.18	6.69	5.78	5.78	6.08	11.86	23.31	17.26	12.77	4.49
Total, kg-mole/hr	3.72	10.08	18.50	32.30	34.18	39.35	39.35	51.46	32.96	0.99	114.35	147.30	147.30	103.98	251.28	313.19	295.03	218.33	76.70
Density, kg/m3	2.29	3.63	2.19	2.23	2.11	1.38	1.53	2.19	2.19	3.51	1.91	1.81	2.17	1.91	2.05	2.23	1.92	1.91	1.91
Mole Wt.	16.84	18.02	29.45	24.43	23.08	20.05	20.05	29.45	29.45	27.64	25.85	26.85	26.85	25.85	26.43	26.67	25.85	25.85	25.85
Z Factor	1.001	-	1.000	0.998	0.999	1.001	1.000	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

MATERIAL BALANCE - POWER MODULE #1	MC-POWER CORPORATION	JOB NO.: 24024-000	
	20 MW HEFPP PROGRAM	DOCUMENT NO.	REV.
		SHEET 2 OF 2	

TABLE 15
Material Balance – Full Load SOR – -5,000’ Elev./15°C/-29°C Ambient Air (Page 1 of 2)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	802	800	1,061	950	978	978	543	978	1,072	893	978	928	867	978	978	978
Pressure, kPa	698	872	604.1	609.7	608.9	606.5	604.9	604.4	604.1	602.5	602.5	601.9	600.7	602.5	598.6	603.8	603.0	602.5	602.5
Mass Flow, kg/h	63	170	511	745	745	745	745	1,471	960	28	3,130	4,119	4,119	2,962	7,081	8,814	8,087	6,093	1,995
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	83	212	386	682	721	839	839	1,111	725	22	2,616	3,341	3,341	2,476	5,817	7,166	6,759	5,092	1,667
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.03	3.60	2.72	0.09	0.09	0.09	0.06	-	-	-	-	-	-	1.45	-	-	-
CO	-	-	0.41	0.41	0.56	4.70	4.70	1.19	0.77	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	7.95	8.03	8.77	7.26	7.26	22.88	14.93	0.00	6.01	21.77	21.77	5.69	27.47	27.65	15.54	11.71	3.83
H2	-	-	0.63	0.63	4.04	10.41	10.41	1.82	1.19	-	-	-	-	-	-	-	-	-	-
H2O	-	9.46	8.16	17.62	15.99	14.87	14.87	23.47	15.31	0.01	27.03	43.65	43.65	25.58	69.23	69.83	69.83	52.61	17.22
N2	0.07	-	0.04	0.11	0.11	0.11	0.11	0.11	0.07	0.77	75.03	75.87	75.87	71.00	146.87	193.82	193.82	146.02	47.80
O2	-	-	-	-	-	-	-	-	-	0.20	8.66	7.77	7.77	8.20	15.97	28.43	22.37	16.86	5.52
Total, kg-mole/hr	3.72	9.46	17.23	30.41	32.19	37.45	37.45	49.55	32.33	0.99	116.73	149.07	149.07	110.46	259.53	319.72	301.56	227.19	74.37
Density, kg/m3	2.29	3.63	2.21	2.24	2.12	1.37	1.52	2.21	2.21	3.84	1.99	1.86	2.23	1.99	2.12	2.31	1.99	1.99	1.99
Mole Wt.	16.84	18.02	29.69	24.48	23.13	19.88	19.88	29.69	29.69	28.79	26.82	27.63	27.63	26.82	27.28	27.57	26.82	26.82	26.82
Z Factor	1.001	-	1.000	0.999	0.999	1.001	1.001	1.000	1.000	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -29°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	812	805	1,061	950	978	978	463	978	1,072	894	978	930	866	978	978	978
Pressure, kPa	698	872	604.1	609.5	608.8	606.4	604.8	604.4	604.1	602.5	602.5	601.9	600.7	602.5	598.6	603.8	603.0	602.5	602.5
Mass Flow, kg/h	63	149	520	732	732	732	732	1,458	938	29	3,134	4,101	4,101	3,238	7,339	8,856	8,129	6,372	1,757
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	83	185	387	655	695	813	813	1,084	697	22	2,618	3,315	3,315	2,704	6,019	7,196	6,789	5,322	1,468
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.04	3.61	2.73	0.10	0.10	0.10	0.06	-	-	-	-	-	-	4.16	-	-	-
CO	-	-	0.44	0.44	0.64	5.00	5.00	1.24	0.80	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	8.26	8.34	9.02	7.29	7.29	23.16	14.89	0.00	6.80	22.56	22.56	7.02	29.58	29.74	17.63	13.82	3.81
H2	-	-	0.63	0.63	3.95	10.11	10.11	1.77	1.14	-	-	-	-	-	-	-	-	-	-
H2O	-	8.25	7.84	16.10	14.54	13.63	13.63	21.98	14.14	-	27.47	42.87	42.87	28.37	71.24	71.24	71.24	55.84	15.40
N2	0.07	-	0.04	0.12	0.12	0.12	0.12	0.12	0.07	0.78	75.31	76.17	76.17	77.80	153.97	195.35	195.35	153.12	42.23
O2	-	-	-	-	-	-	-	-	-	0.21	7.20	6.32	6.32	7.44	13.76	24.74	18.68	14.65	4.04
Total, kg-mole/hr	3.72	8.25	17.26	29.23	30.99	36.25	36.25	48.36	31.10	0.99	116.78	147.91	147.91	120.64	268.55	321.07	302.90	237.42	65.48
Density, kg/m3	2.29	3.63	2.24	2.26	2.15	1.39	1.55	2.24	2.24	4.52	1.99	1.87	2.24	1.99	2.11	2.31	1.99	1.99	1.99
Mole Wt.	16.84	18.02	30.15	25.03	23.61	20.18	20.18	30.15	30.15	28.90	26.84	27.73	27.73	26.84	27.33	27.58	26.84	26.84	26.84
Z Factor	1.001	-	1.000	0.999	0.999	1.001	1.001	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

MATERIAL BALANCE - POWER MODULE #1	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000	
		DOCUMENT NO.	REV.
		SHEET 1 OF 2	

TABLE 15
Material Balance – Full Load SOR – -5,000’ Elev./49°C (0%/100% Rel. Humidity) Ambient Air (Page 2 of 2)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	806	802	1,061	950	978	978	605	978	1,072	892	978	925	866	978	978	978
Pressure, kPa	698	872	604.3	610.9	609.9	607.0	605.1	604.6	604.3	602.5	602.5	602.0	600.7	602.5	598.6	603.8	603.0	602.5	602.5
Mass Flow, kg/h	63	188	565	816	816	816	816	1,543	978	29	3,176	4,182	4,182	2,719	6,901	8,882	8,156	5,894	2,261
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	83	234	432	750	794	908	908	1,180	748	22	2,636	3,383	3,383	2,257	5,640	7,177	6,770	4,893	1,877
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.03	3.60	2.62	0.07	0.07	0.07	0.04	-	-	-	-	-	-	-	-	-	-
CO	-	-	0.44	0.44	0.60	4.65	4.65	1.21	0.77	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	8.64	8.72	9.53	8.04	8.04	23.59	14.95	0.00	5.42	21.18	21.18	4.64	25.82	26.03	13.92	10.06	3.86
H2	-	-	0.72	0.72	4.47	10.64	10.64	1.97	1.25	-	-	-	-	-	-	-	-	-	-
H2O	-	10.46	9.41	19.86	18.07	17.01	17.01	25.68	16.27	-	24.73	42.33	42.33	21.17	63.50	63.50	63.50	45.89	17.61
N2	0.07	-	0.04	0.12	0.12	0.12	0.12	0.12	0.07	0.78	77.08	77.93	77.93	65.99	143.92	197.96	197.96	143.07	54.89
O2	-	-	-	-	-	-	-	-	-	0.21	10.39	9.50	9.50	8.89	18.39	32.74	26.68	19.28	7.40
Total, kg-mole/hr	3.72	10.46	19.28	33.46	35.41	40.52	40.52	52.63	33.35	0.99	117.61	150.94	150.94	100.69	251.64	320.22	302.06	218.31	83.75
Density, kg/m3	2.29	3.63	2.18	2.23	2.11	1.39	1.54	2.18	2.18	3.46	2.00	1.87	2.24	2.00	2.13	2.32	2.00	2.00	2.00
Mole Wt.	16.84	18.02	29.32	24.40	23.05	20.14	20.14	29.32	29.32	28.90	27.00	27.70	27.70	27.00	27.42	27.74	27.00	27.00	27.00
Z Factor	1.001	-	1.000	0.998	0.999	1.001	1.000	1.000	1.000	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	807	803	1,061	950	978	978	598	978	1,072	891	978	925	866	978	978	978
Pressure, kPa	698	872	603.7	610.5	609.5	606.5	604.5	604.0	603.7	602.5	602.5	601.6	600.4	602.5	598.5	603.7	603.0	602.5	602.5
Mass Flow, kg/h	63	192	575	830	830	830	830	1,557	981	27	2,963	3,971	3,971	2,574	6,545	8,352	7,625	5,537	2,089
Std. Volume Flow, m3/h (0'C, 101.3 kPa)	83	239	441	763	808	921	921	1,193	752	22	2,567	3,318	3,318	2,230	5,548	7,013	6,606	4,796	1,809
Molar Flow, kg-mole/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	3.57	-	0.02	3.60	2.61	0.07	0.07	0.07	0.04	-	-	-	-	-	-	-	-	-	-
CO	-	-	0.45	0.45	0.61	4.64	4.64	1.21	0.76	-	-	-	-	-	-	-	-	-	-
CO2	0.07	-	8.77	8.84	9.67	8.19	8.19	23.72	14.95	0.00	5.43	21.19	21.19	4.72	25.90	26.08	13.97	10.15	3.83
H2	-	-	0.74	0.74	4.55	10.68	10.68	2.00	1.26	-	-	-	-	-	-	-	-	-	-
H2O	-	10.65	9.65	20.30	18.47	17.42	17.42	26.10	16.45	0.11	36.09	54.00	54.00	31.35	85.35	92.88	92.88	67.44	25.44
N2	0.07	-	0.04	0.12	0.12	0.12	0.12	0.12	0.07	0.69	65.72	66.49	66.49	57.10	123.58	169.15	169.15	122.82	46.33
O2	-	-	-	-	-	-	-	-	-	0.18	7.27	6.36	6.36	6.32	12.68	24.77	18.72	13.59	5.13
Total, kg-mole/hr	3.72	10.65	19.67	34.04	36.03	41.11	41.11	53.22	33.54	0.99	114.51	148.03	148.03	99.48	247.51	312.88	294.72	213.99	80.72
Density, kg/m3	2.29	3.63	2.17	2.22	2.11	1.39	1.54	2.17	2.17	3.35	1.92	1.81	2.17	1.92	2.06	2.23	1.92	1.92	1.92
Mole Wt.	16.84	18.02	29.25	24.38	23.03	20.19	20.19	29.25	29.25	27.64	25.87	26.83	26.83	25.87	26.44	26.69	25.87	25.87	25.87
Z Factor	1.001	-	1.000	0.998	0.999	1.001	1.000	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

BECHTEL	MATERIAL BALANCE - POWER MODULE #1	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000 DOCUMENT NO. REV. SHEET 2 OF 2

TABLE 16
Material Balance – Full Load EOR – Sea Level /15°C/49°C (0% Rel. Humidity) Ambient Air

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	805	801	1,061	950	978	978	518	978	1,072	890	978	932	866	978	978	978
Pressure, kPa	698	872	604.6	610.9	609.9	607.2	605.3	604.9	604.6	602.5	602.5	602.4	601.2	602.5	598.8	604.0	603.0	602.5	602.5
Mass Flow, kg/h	63	183	548	794	794	794	794	1,520	972	28	3,083	4,083	4,083	3,781	7,864	9,755	9,028	6,864	2,164
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	83	227	417	728	770	885	885	1,156	739	22	2,571	3,311	3,311	3,153	6,464	7,936	7,529	5,724	1,805
Molar Flow, kg-mole/hr																			
CH4	3.57	-	0.04	3.62	2.66	0.12	0.12	0.12	0.07					-	-	1.45			
CO	-	-	0.41	0.41	0.58	4.61	4.61	1.14	0.73					-	-	-			
CO2	0.07	-	8.43	8.51	9.29	7.81	7.81	23.39	14.95	0.00	5.48	21.24	21.24	6.73	27.97	28.16	16.06	12.21	3.85
H2	-	-	0.66	0.66	4.30	10.46	10.46	1.82	1.17					-	-	-			
H2O	-	10.14	9.01	19.15	17.42	16.36	16.36	24.99	15.98	0.01	25.58	42.88	42.88	31.38	74.26	74.92	74.92	56.96	17.96
N2	0.07	-	0.04	0.12	0.12	0.12	0.12	0.12	0.07	0.77	74.17	75.01	75.01	90.96	165.97	217.19	217.19	165.13	52.06
O2	-	-	-	-	-	-	-	-	-	0.20	9.47	8.58	8.58	11.61	20.19	33.79	27.73	21.09	6.65
Total, kg-mole/hr	3.72	10.14	18.60	32.46	34.37	39.46	39.46	51.57	32.97	0.99	114.70	147.72	147.72	140.68	288.40	354.06	335.90	255.38	80.52
Density, kg/m3	2.29	3.63	2.19	2.24	2.12	1.38	1.54	2.19	2.19	4.02	1.99	1.87	2.24	1.99	2.11	2.31	1.99	1.99	1.99
Mole Wt.	16.84	18.02	29.48	24.45	23.09	20.11	20.11	29.48	29.48	28.79	26.88	27.64	27.64	26.88	27.27	27.55	26.88	26.88	26.88
Z Factor	1.001		1.000	0.998	0.999	1.001	1.000	1.000	1.000	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stream Description:	Natural Gas to PM #1	Steam to PM #1	Anode Recycle	Mixed Feed to Exchanger	Reformer Feed	Reformer Exhaust (Reformate)	Anode Feed	Anode Exhaust	Anode-Exhst. Fuel to Combustor	Air to Combustor	Cathode Recycle to Combustor	Combustor Exhaust	Reformer Flue Gas	Cathode Recycle (Bypass to Blower)	PM #1 Gas to Blower	Cathode Feed	Cathode Exhaust	Cathode Recycle	PM #1 Gas to Gas Turbine
Temperature, K	616	536	978	807	802	1,061	950	978	978	577	978	1,072	890	978	930	866	978	978	978
Pressure, kPa	698	872	604.7	611.8	610.8	607.7	605.6	605.1	604.7	602.5	602.5	602.5	601.2	602.5	598.8	604.0	603.0	602.5	602.5
Mass Flow, kg/h	63	195	585	843	843	843	843	1,570	984	29	3,140	4,153	4,153	3,559	7,713	9,859	9,133	6,700	2,433
Std. Volume Flow, m3/h (0°C, 101.3 kPa)	83	243	449	775	821	933	933	1,204	755	22	2,599	3,354	3,354	2,946	6,300	7,965	7,558	5,545	2,013
Molar Flow, kg-mole/hr																			
CH4	3.57	-	0.04	3.61	2.60	0.10	0.10	0.10	0.06					-	-	4.16			
CO	-	-	0.43	0.43	0.61	4.58	4.58	1.16	0.73					-	-	-			
CO2	0.07	-	8.90	8.98	9.81	8.34	8.34	23.87	14.97	0.00	5.00	20.76	20.76	5.67	26.44	26.66	14.55	10.68	3.88
H2	-	-	0.72	0.72	4.60	10.62	10.62	1.93	1.21					-	-	-			
H2O	-	10.83	9.90	20.73	18.88	17.86	17.86	26.54	16.64	-	23.21	41.19	41.19	26.31	67.50	67.50	67.50	49.52	17.98
N2	0.07	-	0.04	0.12	0.12	0.12	0.12	0.12	0.07	0.78	76.65	77.50	77.50	86.88	164.38	222.90	222.90	163.52	59.38
O2	-	-	-	-	-	-	-	-	-	0.21	11.09	10.20	10.20	12.57	22.77	38.30	32.25	23.66	8.59
Total, kg-mole/hr	3.72	10.83	20.04	34.59	36.62	41.62	41.62	53.72	33.69	0.99	115.95	149.65	149.65	131.43	281.08	355.36	337.20	247.37	89.83
Density, kg/m3	2.29	3.63	2.17	2.23	2.11	1.40	1.55	2.18	2.17	3.62	2.01	1.87	2.25	2.01	2.12	2.32	2.01	2.01	2.01
Mole Wt.	16.84	18.02	29.22	24.38	23.03	20.26	20.26	29.22	29.22	28.90	27.08	27.75	27.75	27.08	27.44	27.74	27.08	27.08	27.08
Z Factor	1.001		1.000	0.998	0.999	1.001	1.000	1.000	1.000	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001

MATERIAL BALANCE - POWER MODULE #1	MC-POWER CORPORATION 20 MW HEFPP PROGRAM	JOB NO.: 24024-000 DOCUMENT NO. SHEET 1 OF 2	REV.

TABLE 17
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 17
(Page 2 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	329.36	329.36		11.08	340.31	0.13	340.31
Mass Flow kg/h	5933.5	5933.5		199.5	6130.8	2.3	6130.8
Enthalpy kJ/h	-1.161E+07	-9.823E+06	1.783E+06	1.965E+05	-9.629E+06	1.577E+03	-9.628E+06
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2008
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	329.361	329.361		11.077	340.312	0.126	340.312
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	329.361	329.361		11.077	340.312	0.126	340.312

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	340.31		340.31			0.38	339.93
Mass Flow kg/h	6130.8		6130.8			6.8	6123.9
Enthalpy kJ/h	-9.616E+06	1.206E+04	-8.557E+06	1.059E+06	1.349E+07	-8.494E+03	4.940E+06
Density kg/m3	944.6235		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	340.312		340.312			0.378	339.934
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	340.312		340.312			0.378	339.934

TABLE 17
(Page 4 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	288	518		518
Pressure kPa	896		896	101	621		621
Molar Flow kgmole/h	339.93		328.86	2101.94	2101.94		0.99
Mass Flow kg/h	6123.9		5924.4	60507.2	60507.2		28.4
Enthalpy kJ/h	6.030E+06	1.090E+06	5.834E+06	1.761E+07	3.189E+07	1.427E+07	1.499E+04
Density kg/m3	3.7298		3.7298	1.2105	4.1419		4.1419
Mole Wt.	18.0151		18.0151	28.7863	28.7863		28.7863
Spec. Heat kJ/kg-C	2.0458		2.0458	1.015	1.0499		1.0499
Therm Cond W/m-K	0.0404		0.0404	0.0251	0.0399		0.0399
Viscosity cP	0.0186		0.0186	0.0182	0.0279		0.0279
Z Factor	0.9716		0.9716	0.9992	1.0016		1.0016
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	6.306	6.306		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	339.934		328.858	21.019	21.019		0.010
N2	0.000		0.000	1639.516	1639.516		0.771
O2	0.000		0.000	435.102	435.102		0.205
TOTAL, kg-mol/h	339.934		328.858	2101.944	2101.944		0.988

TABLE 17
(Page 5 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	518	978	978	671		656	643
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	688.79	2564.80	2564.80	2564.80		2564.80	2564.80
Mass Flow kg/h	19827.8	68687.6	68687.6	68687.6		68687.6	68687.6
Enthalpy kJ/h	1.045E+07	8.072E+07	8.072E+07	5.350E+07	2.722E+07	5.229E+07	5.120E+07
Density kg/m3	4.1419	1.9831	1.9534	0.5034		0.5109	0.5177
Mole Wt.	28.7863	26.7809	26.7809	26.7809		26.7809	26.7809
Spec. Heat kJ/kg-C	1.0499	1.3403	1.3403	1.2421		1.2376	1.2335
Therm Cond W/m-K	0.0399	0.0694	0.0693	0.0493		0.0483	0.0474
Viscosity cP	0.0279	0.0386	0.0386	0.0292		0.0288	0.0284
Z Factor	1.0016	1.0012	1.0012	1.0001		1.0001	1.0001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	2.066	137.662	137.662	137.662		137.662	137.662
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	6.888	607.225	607.225	607.225		607.225	607.225
N2	537.258	1642.171	1642.171	1642.171		1642.171	1642.171
O2	142.580	177.745	177.745	177.745		177.745	177.745
TOTAL, kg-mol/h	688.792	2564.803	2564.803	2564.803		2564.803	2564.803

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	481	468	446	978	978	837	801
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2564.80	2564.80	2564.80	16.56	16.56	25.69	29.42
Mass Flow kg/h	68687.6	68687.6	68687.6	493.7	493.7	658.3	721.0
Enthalpy kJ/h	3.771E+07	3.665E+07	3.487E+07	6.246E+05	6.246E+05	7.867E+05	8.757E+05
Density kg/m3	0.6882	0.7026	0.7324	2.1927	2.1927	2.2372	2.237
Mole Wt.	26.7809	26.7809	26.7809	29.8177	29.8177	25.6212	24.51
Spec. Heat kJ/kg-C	1.1857	1.1823	1.1768	1.5567	1.5567	1.6725	1.8334
Therm Cond W/m-K	0.0362	0.0354	0.0338	0.0795	0.0795	0.0696	0.0727
Viscosity cP	0.023	0.0225	0.0217	0.0368	0.0368	0.0292	0.0279
Z Factor	0.9995	0.9995	0.9993	1.0001	1.0001	0.9982	0.9985
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.032	0.032	0.032	3.607
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.401	0.401	0.401	0.401
CO2	137.662	137.662	137.662	7.722	7.722	7.722	7.797
H2	0.000	0.000	0.000	0.603	0.603	0.603	0.603
H2O	607.225	607.225	607.225	7.760	7.760	16.895	16.895
N2	1642.171	1642.171	1642.171	0.039	0.039	0.039	0.113
O2	177.745	177.745	177.745	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2564.803	2564.803	2564.803	16.557	16.557	25.692	29.416

TABLE 17
(Page 7 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	920	799	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	29.42	31.13	36.44		36.44		48.55
Mass Flow kg/h	721.0	721.0	721.0		721.0		1447.5
Enthalpy kJ/h	1.036E+06	8.990E+05	1.340E+06	1.019E+06	1.180E+06	1.797E+06	1.831E+06
Density kg/m3	1.9349	2.1031	1.3507		1.5004		2.1927
Mole Wt.	24.51	23.159	19.7859		19.7859		29.8177
Spec. Heat kJ/kg-C	1.914	1.8619	2.0299		1.979		1.5567
Therm Cond W/m-K	0.0845	0.0848	0.1324		0.1211		0.0795
Viscosity cP	0.0319	0.0285	0.0338		0.0312		0.0368
Z Factor	0.9995	0.9991	1.0007		1.0005		1.0001
Component Flow, kg-mol/h							
CH4	3.607	2.749	0.095		0.095		0.095
C2H6							
C3H8							
n-C4H10							
CO	0.401	0.540	4.714		4.714		1.175
CO2	7.797	8.515	6.995		6.995		22.642
H2	0.603	3.895	10.337		10.337		1.768
H2O	16.895	15.319	14.185		14.185		22.754
N2	0.113	0.113	0.113		0.113		0.113
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	29.416	31.131	36.439		36.439		48.547

TABLE 17
(Page 8 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	31.99	230.14	230.15	113.88	116.26	149.24	148.27
Mass Flow kg/h	953.8	6163.5	6163.5	3049.8	3113.6	4095.9	4095.9
Enthalpy kJ/h	1.207E+06	7.244E+06	7.244E+06	3.584E+06	3.659E+06	4.881E+06	5.427E+06
Density kg/m3	2.1927	1.9831	1.9831	1.9831	1.9831	2.0217	1.8486
Mole Wt.	29.8177	26.7809	26.7809	26.7809	26.7809	27.4451	27.6245
Spec. Heat kJ/kg-C	1.5567	1.3403	1.3403	1.3403	1.3403	1.3885	1.4168
Therm Cond W/m-K	0.0795	0.0694	0.0694	0.0694	0.0694	0.0714	0.076
Viscosity cP	0.0368	0.0386	0.0386	0.0386	0.0386	0.0377	0.0404
Z Factor	1.0001	1.0012	1.0012	1.0012	1.0012	1.001	1.001
Component Flow, kg-mol/h							
CH4	0.063	0.000	0.000	0.000	0.000	0.063	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.774	0.000	0.000	0.000	0.000	0.774	0.000
CO2	14.920	12.353	12.353	6.112	6.240	21.163	22.000
H2	1.165	0.000	0.000	0.000	0.000	1.165	0.000
H2O	14.994	54.488	54.488	26.962	27.526	42.529	43.819
N2	0.074	147.355	147.356	72.915	74.440	75.285	75.285
O2	0.000	15.949	15.950	7.892	8.057	8.262	7.167
TOTAL, kg-mol/h	31.989	230.145	230.146	113.881	116.264	149.241	148.272

TABLE 17
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	893	929	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	148.27	262.15	3834.63	3834.63		301.39	71.24
Mass Flow kg/h	4095.9	7145.8	105577.0	105577.0		8071.5	1908.0
Enthalpy kJ/h	4.408E+06	7.992E+06	1.064E+08	1.067E+08	3.841E+05	9.486E+06	2.242E+06
Density kg/m3	2.2173	2.1035	2.2841	2.3003		1.9831	1.9831
Mole Wt.	27.6245	27.258	27.5325	27.5325		26.7809	26.7809
Spec. Heat kJ/kg-C	1.3602	1.3523	1.2931	1.294		1.3403	1.3403
Therm Cond W/m-K	0.065	0.0669	0.0622	0.0624		0.0694	0.0694
Viscosity cP	0.0353	0.0366	0.0355	0.0356		0.0386	0.0386
Z Factor	1.0009	1.001	1.0011	1.0011		1.0012	1.0012
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	22.000	28.112	339.413	339.413		16.177	3.824
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	43.819	70.781	856.262	856.262		71.355	16.867
N2	75.285	148.200	2315.662	2315.662		192.972	45.616
O2	7.167	15.059	323.289	323.289		20.887	4.937
TOTAL, kg-mol/h	148.272	262.153	3834.627	3834.627		301.391	71.245

TABLE 18
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 18
(Page 2 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	288.08	288.08		9.70	297.66	0.13	297.66
Mass Flow kg/h	5189.9	5189.9		174.8	5362.4	2.3	5362.4
Enthalpy kJ/h	-1.015E+07	-8.592E+06	1.560E+06	1.721E+05	-8.422E+06	1.580E+03	-8.422E+06
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2016
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	288.084	288.084		9.702	297.660	0.126	297.660
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	288.084	288.084		9.702	297.660	0.126	297.660

TABLE 18
(Page 3 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	297.66		297.66			0.38	297.28
Mass Flow kg/h	5362.4		5362.4			6.8	5355.6
Enthalpy kJ/h	-8.411E+06	1.054E+04	-7.485E+06	9.263E+05	1.180E+07	-8.494E+03	4.320E+06
Density kg/m3	944.6243		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	297.660		297.660			0.378	297.282
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	297.660		297.660			0.378	297.282

TABLE 18
(Page 4 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	244	441		441
Pressure kPa	896		896	101	621		621
Molar Flow kgmole/h	297.28		287.58	1861.96	1861.96		0.99
Mass Flow kg/h	5355.6		5180.8	53801.6	53801.6		28.5
Enthalpy kJ/h	5.273E+06	9.531E+05	5.101E+06	1.320E+07	2.393E+07	1.073E+07	1.270E+04
Density kg/m3	3.7298		3.7298	1.4343	4.8815		4.8815
Mole Wt.	18.0151		18.0151	28.8951	28.8951		28.8951
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0083	1.0311		1.0311
Therm Cond W/m-K	0.0404		0.0404	0.022	0.0353		0.0353
Viscosity cP	0.0186		0.0186	0.0161	0.025		0.025
Z Factor	0.9716		0.9716	0.9985	1.0011		1.0011
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	5.642	5.642		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	297.282		287.580	0.000	0.000		0.000
N2	0.000		0.000	1466.999	1466.999		0.778
O2	0.000		0.000	389.319	389.319		0.207
TOTAL, kg-mol/h	297.282		287.580	1861.960	1861.960		0.988

TABLE 18
(Page 5 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	441	978	978	671		655	643
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	608.80	2283.58	2283.58	2283.58		2283.58	2283.58
Mass Flow kg/h	17591.3	61239.5	61239.5	61239.5		61239.5	61239.5
Enthalpy kJ/h	7.824E+06	7.204E+07	7.204E+07	4.779E+07	2.425E+07	4.658E+07	4.563E+07
Density kg/m3	4.8815	1.9858	1.9561	0.5034		0.5123	0.5189
Mole Wt.	28.8951	26.8173	26.8173	26.8173		26.8173	26.8173
Spec. Heat kJ/kg-C	1.0311	1.3431	1.343	1.2444		1.2393	1.2352
Therm Cond W/m-K	0.0353	0.0693	0.0693	0.0493		0.0482	0.0473
Viscosity cP	0.025	0.0386	0.0386	0.0292		0.0287	0.0283
Z Factor	1.0011	1.0012	1.0012	1.0001		1.0001	1
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	1.845	136.999	136.999	136.999		136.999	136.999
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	0.000	544.933	544.933	544.933		544.933	544.933
N2	479.659	1469.681	1469.681	1469.681		1469.681	1469.681
O2	127.294	131.968	131.968	131.968		131.968	131.968
TOTAL, kg-mol/h	608.797	2283.581	2283.581	2283.581		2283.581	2283.581

TABLE 18
(Page 6 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	484	471	450	978	978	851	811
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2283.58	2283.58	2283.58	16.64	16.64	24.63	28.35
Mass Flow kg/h	61239.5	61239.5	61239.5	503.7	503.7	647.6	710.3
Enthalpy kJ/h	3.383E+07	3.290E+07	3.134E+07	6.295E+05	6.295E+05	7.712E+05	8.602E+05
Density kg/m3	0.6852	0.6991	0.7277	2.2258	2.2258	2.2591	2.2578
Mole Wt.	26.8173	26.8173	26.8173	30.2698	30.2698	26.2949	25.0535
Spec. Heat kJ/kg-C	1.1879	1.1846	1.1791	1.5402	1.5402	1.647	1.8142
Therm Cond W/m-K	0.0364	0.0355	0.034	0.0791	0.0791	0.0705	0.0736
Viscosity cP	0.0231	0.0226	0.0218	0.037	0.037	0.0303	0.0287
Z Factor	0.9995	0.9995	0.9993	1.0002	1.0002	0.9985	0.9988
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.037	0.037	0.037	3.612
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.431	0.431	0.431	0.431
CO2	136.999	136.999	136.999	8.037	8.036	8.037	8.111
H2	0.000	0.000	0.000	0.601	0.601	0.601	0.601
H2O	544.933	544.933	544.933	7.494	7.494	15.482	15.482
N2	1469.681	1469.681	1469.681	0.040	0.040	0.040	0.115
O2	131.968	131.968	131.968	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2283.581	2283.581	2283.581	16.640	16.640	24.628	28.352

TABLE 18
(Page 7 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	929	804	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	28.35	30.05	35.36		35.36		47.47
Mass Flow kg/h	710.3	710.3	710.3		710.3		1436.9
Enthalpy kJ/h	1.016E+06	8.777E+05	1.300E+06	1.009E+06	1.144E+06	1.797E+06	1.796E+06
Density kg/m3	1.9573	2.1308	1.3712		1.5232		2.2258
Mole Wt.	25.0535	23.6345	20.0872		20.0872		30.2698
Spec. Heat kJ/kg-C	1.8932	1.8389	1.9991		1.9492		1.5402
Therm Cond W/m-K	0.0853	0.0853	0.1318		0.1206		0.0791
Viscosity cP	0.0324	0.0289	0.0341		0.0314		0.037
Z Factor	0.9997	0.9993	1.0007		1.0006		1.0002
Component Flow, kg-mol/h							
CH4	3.612	2.761	0.107		0.107		0.107
C2H6							
C3H8							
n-C4H10							
CO	0.431	0.621	5.008		5.008		1.228
CO2	8.111	8.772	7.038		7.038		22.926
H2	0.601	3.815	10.043		10.043		1.715
H2O	15.482	13.971	13.050		13.050		21.378
N2	0.115	0.115	0.115		0.115		0.115
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	28.352	30.054	35.361		35.361		47.469

TABLE 18
(Page 8 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	30.83	239.48	239.48	123.08	116.41	148.22	147.27
Mass Flow kg/h	933.2	6422.2	6422.2	3300.6	3121.7	4083.4	4083.4
Enthalpy kJ/h	1.166E+06	7.555E+06	7.555E+06	3.883E+06	3.672E+06	4.851E+06	5.397E+06
Density kg/m3	2.2258	1.9858	1.9858	1.9858	1.9858	2.0302	1.8555
Mole Wt.	30.2698	26.8173	26.8173	26.8173	26.8173	27.5492	27.728
Spec. Heat kJ/kg-C	1.5402	1.3431	1.3431	1.3431	1.3431	1.3857	1.4143
Therm Cond W/m-K	0.0791	0.0693	0.0693	0.0693	0.0693	0.0712	0.0759
Viscosity cP	0.037	0.0386	0.0386	0.0386	0.0386	0.0377	0.0404
Z Factor	1.0002	1.0012	1.0012	1.0012	1.0012	1.001	1.001
Component Flow, kg-mol/h							
CH4	0.069	0.000	0.000	0.000	0.000	0.069	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.798	0.000	0.000	0.000	0.000	0.798	0.000
CO2	14.889	14.367	14.367	7.384	6.984	21.876	22.743
H2	1.114	0.000	0.000	0.000	0.000	1.114	0.000
H2O	13.884	57.148	57.148	29.370	27.778	41.662	42.915
N2	0.074	154.127	154.127	79.210	74.917	75.770	75.770
O2	0.000	13.840	13.840	7.113	6.727	6.934	5.839
TOTAL, kg-mol/h	30.829	239.481	239.481	123.075	116.406	148.223	147.267

TABLE 18
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / -20°C AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	894	931	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	147.27	270.34	3852.91	3852.91		302.91	63.43
Mass Flow kg/h	4083.4	7384.0	106199.0	106199.0		8123.3	1701.1
Enthalpy kJ/h	4.388E+06	8.271E+06	1.071E+08	1.075E+08	3.859E+05	9.556E+06	2.001E+06
Density kg/m3	2.2232	2.1025	2.2866	2.3029		1.9858	1.9858
Mole Wt.	27.728	27.3134	27.5633	27.5633		26.8173	26.8173
Spec. Heat kJ/kg-C	1.3579	1.3519	1.2954	1.2963		1.3431	1.3431
Therm Cond W/m-K	0.065	0.067	0.0622	0.0623		0.0693	0.0693
Viscosity cP	0.0353	0.0367	0.0354	0.0355		0.0386	0.0386
Z Factor	1.0009	1.001	1.0011	1.0011		1.0012	1.0012
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	22.743	30.127	363.367	363.367		18.173	3.806
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	42.915	72.285	867.415	867.415		72.285	15.137
N2	75.770	154.980	2339.415	2339.415		194.951	40.824
O2	5.839	12.951	282.711	282.711		17.505	3.666
TOTAL, kg-mol/h	147.267	270.343	3852.908	3852.908		302.914	63.433

TABLE 19
Stream Summary Information (Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 19
(Page 2 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	358.85	358.85		12.06	370.78	0.13	370.78
Mass Flow kg/h	6464.6	6464.6		217.2	6679.6	2.3	6679.6
Enthalpy kJ/h	-1.265E+07	-1.070E+07	1.943E+06	2.139E+05	-1.049E+07	1.568E+03	-1.049E+07
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2007
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	358.845	358.845		12.057	370.777	0.125	370.777
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	358.845	358.845		12.057	370.777	0.125	370.777

TABLE 19
(Page 3 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	370.78		370.78			0.38	370.40
Mass Flow kg/h	6679.6		6679.6			6.8	6672.8
Enthalpy kJ/h	-1.048E+07	1.313E+04	-9.323E+06	1.154E+06	1.470E+07	-8.494E+03	5.383E+06
Density kg/m3	944.6234		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	370.777		370.777			0.378	370.400
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	370.777		370.777			0.378	370.400

TABLE 19
(Page 4 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	322	577		577
Pressure kPa	896		896	101	621		621
Molar Flow kgmole/h	370.40		358.34	2363.47	2363.47		0.99
Mass Flow kg/h	6672.8		6455.6	68292.7	68292.7		28.5
Enthalpy kJ/h	6.570E+06	1.188E+06	6.357E+06	2.212E+07	4.004E+07	1.792E+07	1.674E+04
Density kg/m3	3.7298		3.7298	1.0867	3.7303		3.7303
Mole Wt.	18.0151		18.0151	28.8951	28.8951		28.8951
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0118	1.0557		1.0557
Therm Cond W/m-K	0.0404		0.0404	0.0275	0.0434		0.0434
Viscosity cP	0.0186		0.0186	0.0199	0.0304		0.0304
Z Factor	0.9716		0.9716	0.9997	1.0019		1.0019
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	7.162	7.162		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	370.400		358.342	0.000	0.000		0.000
N2	0.000		0.000	1862.127	1862.127		0.778
O2	0.000		0.000	494.180	494.180		0.207
TOTAL, kg-mol/h	370.400		358.342	2363.469	2363.469		0.988

TABLE 19
(Page 5 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	577	978	978	669		656	643
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	775.97	2855.88	2855.88	2855.88		2855.88	2855.88
Mass Flow kg/h	22421.7	77006.5	77006.5	77006.5		77006.5	77006.5
Enthalpy kJ/h	1.315E+07	8.941E+07	8.941E+07	5.914E+07	3.027E+07	5.793E+07	5.674E+07
Density kg/m3	3.7303	1.9966	1.9667	0.5081		0.5146	0.5213
Mole Wt.	28.8951	26.9642	26.9642	26.9642		26.9642	26.9642
Spec. Heat kJ/kg-C	1.0557	1.3215	1.3215	1.2255		1.2215	1.2176
Therm Cond W/m-K	0.0434	0.069	0.069	0.0491		0.0482	0.0474
Viscosity cP	0.0304	0.0392	0.0392	0.0295		0.0291	0.0287
Z Factor	1.0019	1.0012	1.0012	1.0001		1.0001	1.0001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	2.351	138.525	138.525	138.525		138.525	138.525
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	0.000	615.679	615.680	615.680		615.680	615.680
N2	611.368	1864.842	1864.842	1864.842		1864.842	1864.842
O2	162.248	236.834	236.834	236.834		236.834	236.834
TOTAL, kg-mol/h	775.967	2855.880	2855.880	2855.880		2855.880	2855.880

TABLE 19
(Page 6 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	484	471	449	978	978	838	804
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2855.88	2855.88	2855.88	18.24	18.24	28.19	31.91
Mass Flow kg/h	77006.5	77006.5	77006.5	538.0	538.0	717.3	780.0
Enthalpy kJ/h	4.204E+07	4.089E+07	3.895E+07	6.865E+05	6.865E+05	8.630E+05	9.520E+05
Density kg/m3	0.6893	0.7033	0.7323	2.1694	2.1694	2.2199	2.2218
Mole Wt.	26.9642	26.9642	26.9642	29.5002	29.5002	25.4448	24.441
Spec. Heat kJ/kg-C	1.1717	1.1685	1.1632	1.5681	1.5681	1.6812	1.8297
Therm Cond W/m-K	0.0365	0.0357	0.0342	0.0798	0.0798	0.0699	0.0726
Viscosity cP	0.0234	0.0229	0.0221	0.0366	0.0366	0.0291	0.028
Z Factor	0.9996	0.9996	0.9994	1.0001	1.0001	0.9982	0.9984
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.028	0.028	0.028	3.602
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.428	0.428	0.428	0.428
CO2	138.525	138.525	138.525	8.296	8.296	8.296	8.370
H2	0.000	0.000	0.000	0.677	0.677	0.677	0.677
H2O	615.680	615.680	615.680	8.766	8.766	18.720	18.720
N2	1864.842	1864.842	1864.842	0.041	0.041	0.041	0.116
O2	236.834	236.834	236.834	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2855.880	2855.880	2855.880	18.236	18.236	28.190	31.913

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	923	801	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	31.91	33.78	38.96		38.96		51.07
Mass Flow kg/h	780.0	780.0	780.0		780.0		1506.6
Enthalpy kJ/h	1.125E+06	9.759E+05	1.441E+06	1.030E+06	1.268E+06	1.797E+06	1.922E+06
Density kg/m3	1.9233	2.0914	1.3667		1.5182		2.1694
Mole Wt.	24.441	23.0936	20.0194		20.0194		29.5002
Spec. Heat kJ/kg-C	1.9083	1.8574	2.0197		1.9688		1.5681
Therm Cond W/m-K	0.0844	0.0847	0.1298		0.1187		0.0798
Viscosity cP	0.032	0.0285	0.0339		0.0313		0.0366
Z Factor	0.9995	0.999	1.0006		1.0004		1.0001
Component Flow, kg-mol/h							
CH4	3.602	2.671	0.078		0.078		0.078
C2H6							
C3H8							
n-C4H10							
CO	0.428	0.579	4.676		4.676		1.199
CO2	8.370	9.150	7.647		7.647		23.232
H2	0.677	4.250	10.527		10.527		1.897
H2O	18.720	17.009	15.919		15.919		24.549
N2	0.116	0.116	0.116		0.116		0.116
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	31.913	33.775	38.962		38.962		51.070

TABLE 19
(Page 8 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	32.83	222.86	222.86	105.46	117.40	151.22	150.22
Mass Flow kg/h	968.6	6009.1	6009.1	2843.7	3165.5	4162.6	4162.6
Enthalpy kJ/h	1.236E+06	6.977E+06	6.977E+06	3.302E+06	3.675E+06	4.928E+06	5.476E+06
Density kg/m3	2.1694	1.9966	1.9966	1.9966	1.9966	2.027	1.8543
Mole Wt.	29.5002	26.9642	26.9642	26.9642	26.9642	27.5274	27.7098
Spec. Heat kJ/kg-C	1.5681	1.3215	1.3215	1.3215	1.3215	1.3769	1.4046
Therm Cond W/m-K	0.0798	0.069	0.069	0.069	0.069	0.0712	0.0758
Viscosity cP	0.0366	0.0392	0.0392	0.0392	0.0392	0.038	0.0407
Z Factor	1.0001	1.0012	1.0012	1.0012	1.0012	1.001	1.0011
Component Flow, kg-mol/h							
CH4	0.050	0.000	0.000	0.000	0.000	0.050	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.771	0.000	0.000	0.000	0.000	0.771	0.000
CO2	14.936	10.810	10.810	5.115	5.694	20.633	21.454
H2	1.219	0.000	0.000	0.000	0.000	1.219	0.000
H2O	15.783	48.044	48.044	22.735	25.308	41.091	42.411
N2	0.074	145.522	145.521	68.864	76.658	77.511	77.511
O2	0.000	18.481	18.481	8.746	9.736	9.942	8.847
TOTAL, kg-mol/h	32.834	222.857	222.855	105.461	117.396	151.218	150.223

TABLE 19
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	892	926	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	150.22	255.68	3844.17	3844.17		302.19	79.33
Mass Flow kg/h	4162.6	7006.3	106497.2	106497.2		8148.2	2139.1
Enthalpy kJ/h	4.446E+06	7.747E+06	1.061E+08	1.065E+08	3.850E+05	9.461E+06	2.484E+06
Density kg/m3	2.2255	2.1197	2.2982	2.3145		1.9966	1.9966
Mole Wt.	27.7098	27.4023	27.7036	27.7036		26.9642	26.9642
Spec. Heat kJ/kg-C	1.3487	1.3383	1.2768	1.2777		1.3215	1.3215
Therm Cond W/m-K	0.0648	0.0666	0.062	0.0622		0.069	0.069
Viscosity cP	0.0355	0.0368	0.0359	0.036		0.0392	0.0392
Z Factor	1.0009	1.0011	1.0012	1.0012		1.0012	1.0012
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	21.454	26.569	321.184	321.184		14.658	3.848
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	42.411	65.146	781.753	781.753		65.146	17.102
N2	77.511	146.375	2367.865	2367.865		197.322	51.801
O2	8.847	17.593	373.364	373.364		25.060	6.579
TOTAL, kg-mol/h	150.223	255.683	3844.166	3844.166		302.185	79.330

TABLE 20
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 20
(Page 2 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	363.38	363.38		12.21	375.46	0.13	375.46
Mass Flow kg/h	6546.3	6546.3		219.9	6764.0	2.3	6764.0
Enthalpy kJ/h	-1.281E+07	-1.084E+07	1.967E+06	2.166E+05	-1.062E+07	1.576E+03	-1.062E+07
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2007
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	363.381	363.381		12.209	375.464	0.126	375.464
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	363.381	363.381		12.209	375.464	0.126	375.464

TABLE 20
(Page 3 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	375.46		375.46			0.38	375.09
Mass Flow kg/h	6764.0		6764.0			6.8	6757.2
Enthalpy kJ/h	-1.061E+07	1.330E+04	-9.441E+06	1.168E+06	1.488E+07	-8.494E+03	5.451E+06
Density kg/m3	944.6234		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	375.464		375.464			0.378	375.086
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	375.464		375.464			0.378	375.086

TABLE 20
(Page 4 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	322	571		571
Pressure kPa	896		896	101	621		621
Molar Flow kgmole/h	375.09		362.88	2264.14	2264.14		0.99
Mass Flow kg/h	6757.2		6537.3	62585.1	62585.1		27.3
Enthalpy kJ/h	6.654E+06	1.203E+06	6.437E+06	2.152E+07	3.859E+07	1.707E+07	1.684E+04
Density kg/m3	3.7298		3.7298	1.0407	3.6101		3.6101
Mole Wt.	18.0151		18.0151	27.6418	27.6418		27.6418
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0777	1.1275		1.1275
Therm Cond W/m-K	0.0404		0.0404	0.0267	0.0431		0.0431
Viscosity cP	0.0186		0.0186	0.0182	0.028		0.028
Z Factor	0.9716		0.9716	0.9986	1.0009		1.0009
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	6.071	6.071		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	375.086		362.878	260.811	260.811		0.114
N2	0.000		0.000	1578.383	1578.383		0.689
O2	0.000		0.000	418.879	418.879		0.183
TOTAL, kg-mol/h	375.086		362.878	2264.143	2264.143		0.988

TABLE 20
(Page 5 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	571	978	978	674		661	648
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	742.86	2761.06	2761.06	2761.06		2761.06	2761.06
Mass Flow kg/h	20534.0	71379.3	71379.3	71379.3		71379.3	71379.3
Enthalpy kJ/h	1.266E+07	8.801E+07	8.801E+07	5.862E+07	2.939E+07	5.741E+07	5.621E+07
Density kg/m3	3.6101	1.9148	1.8861	0.4832		0.4895	0.496
Mole Wt.	27.6418	25.8522	25.8522	25.8522		25.8522	25.8522
Spec. Heat kJ/kg-C	1.1275	1.4117	1.4117	1.3064		1.3019	1.2974
Therm Cond W/m-K	0.0431	0.0708	0.0708	0.05		0.049	0.0481
Viscosity cP	0.028	0.0371	0.0371	0.0284		0.028	0.0276
Z Factor	1.0009	1.001	1.0009	1		1	0.9999
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	1.992	137.429	137.429	137.429		137.429	137.429
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	85.571	881.045	881.045	881.045		881.045	881.045
N2	517.863	1581.061	1581.061	1581.061		1581.061	1581.061
O2	137.433	161.523	161.523	161.523		161.523	161.523
TOTAL, kg-mol/h	742.858	2761.058	2761.058	2761.058		2761.058	2761.058

TABLE 20
(Page 6 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	484	471	449	978	978	838	804
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2761.06	2761.06	2761.06	18.50	18.50	28.58	32.30
Mass Flow kg/h	71379.3	71379.3	71379.3	544.8	544.8	726.4	789.1
Enthalpy kJ/h	4.132E+07	4.016E+07	3.819E+07	6.960E+05	6.960E+05	8.748E+05	9.638E+05
Density kg/m3	0.6601	0.674	0.7028	2.166	2.166	2.2174	2.2195
Mole Wt.	25.8522	25.8522	25.8522	29.4533	29.4533	25.4186	24.4299
Spec. Heat kJ/kg-C	1.2446	1.2409	1.2348	1.5699	1.5699	1.6825	1.8293
Therm Cond W/m-K	0.0363	0.0353	0.0337	0.0798	0.0798	0.0699	0.0726
Viscosity cP	0.022	0.0214	0.0204	0.0366	0.0366	0.0291	0.028
Z Factor	0.9993	0.9992	0.999	1.0001	1.0001	0.9982	0.9984
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.027	0.027	0.027	3.601
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.432	0.432	0.432	0.432
CO2	137.429	137.429	137.429	8.382	8.382	8.382	8.457
H2	0.000	0.000	0.000	0.688	0.688	0.688	0.688
H2O	881.045	881.045	881.045	8.925	8.925	19.005	19.005
N2	1581.061	1581.061	1581.061	0.042	0.042	0.042	0.116
O2	161.523	161.523	161.523	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2761.058	2761.058	2761.058	18.496	18.496	28.576	32.299

TABLE 20
(Page 7 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	923	801	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	32.30	34.18	39.35		39.35		51.46
Mass Flow kg/h	789.1	789.1	789.1		789.1		1515.6
Enthalpy kJ/h	1.139E+06	9.878E+05	1.456E+06	1.032E+06	1.281E+06	1.797E+06	1.936E+06
Density kg/m3	1.9216	2.0897	1.369		1.5207		2.166
Mole Wt.	24.4299	23.083	20.0519		20.0519		29.4533
Spec. Heat kJ/kg-C	1.9077	1.8569	2.0184		1.9675		1.5699
Therm Cond W/m-K	0.0844	0.0847	0.1294		0.1184		0.0798
Viscosity cP	0.032	0.0286	0.0339		0.0313		0.0366
Z Factor	0.9995	0.999	1.0006		1.0004		1.0001
Component Flow, kg-mol/h							
CH4	3.601	2.659	0.075		0.075		0.075
C2H6							
C3H8							
n-C4H10							
CO	0.432	0.585	4.669		4.669		1.202
CO2	8.457	9.246	7.745		7.745		23.321
H2	0.688	4.305	10.555		10.555		1.915
H2O	19.005	17.273	16.190		16.190		24.830
N2	0.116	0.116	0.116		0.116		0.116
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	32.299	34.184	39.352		39.352		51.459

TABLE 20
(Page 8 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	32.96	218.33	218.33	103.98	114.35	148.30	147.30
Mass Flow kg/h	970.9	5644.3	5644.3	2688.2	2956.1	3954.3	3954.3
Enthalpy kJ/h	1.240E+06	6.959E+06	6.959E+06	3.314E+06	3.645E+06	4.902E+06	5.450E+06
Density kg/m3	2.166	1.9148	1.9148	1.9148	1.9148	1.9641	1.7967
Mole Wt.	29.4533	25.8522	25.8522	25.8522	25.8522	26.6645	26.8452
Spec. Heat kJ/kg-C	1.5699	1.4117	1.4117	1.4117	1.4117	1.4485	1.4785
Therm Cond W/m-K	0.0798	0.0708	0.0708	0.0708	0.0708	0.0727	0.0774
Viscosity cP	0.0366	0.0371	0.0371	0.0371	0.0371	0.0367	0.0392
Z Factor	1.0001	1.001	1.001	1.001	1.001	1.0008	1.0009
Component Flow, kg-mol/h							
CH4	0.048	0.000	0.000	0.000	0.000	0.048	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.770	0.000	0.000	0.000	0.000	0.770	0.000
CO2	14.939	10.867	10.867	5.176	5.692	20.633	21.451
H2	1.227	0.000	0.000	0.000	0.000	1.227	0.000
H2O	15.905	69.669	69.669	33.181	36.488	52.507	53.830
N2	0.074	125.022	125.022	59.544	65.479	66.242	66.242
O2	0.000	12.772	12.772	6.083	6.689	6.872	5.777
TOTAL, kg-mol/h	32.963	218.330	218.330	103.983	114.347	148.299	147.300

TABLE 20
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - SEA LEVEL / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	892	926	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	147.30	251.28	3758.26	3758.26		295.03	76.70
Mass Flow kg/h	3954.3	6642.5	100243.9	100243.9		7627.1	1982.8
Enthalpy kJ/h	4.418E+06	7.733E+06	1.055E+08	1.058E+08	3.763E+05	9.404E+06	2.445E+06
Density kg/m3	2.1577	2.0455	2.2133	2.2292		1.9148	1.9148
Mole Wt.	26.8452	26.4343	26.673	26.673		25.8522	25.8522
Spec. Heat kJ/kg-C	1.4178	1.416	1.355	1.356		1.4117	1.4117
Therm Cond W/m-K	0.066	0.068	0.0633	0.0635		0.0708	0.0708
Viscosity cP	0.0344	0.0354	0.0343	0.0344		0.0371	0.0371
Z Factor	1.0006	1.0008	1.0008	1.0008		1.001	1.001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	21.451	26.626	321.509	321.509		14.685	3.817
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	53.830	87.011	1129.705	1129.705		94.142	24.473
N2	66.242	125.785	2027.287	2027.287		168.941	43.918
O2	5.777	11.860	279.757	279.757		17.259	4.487
TOTAL, kg-mol/h	147.300	251.283	3758.258	3758.258		295.027	76.696

TABLE 21
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 21
(Page 2 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	341.15	341.15		11.47	352.50	0.13	352.50
Mass Flow kg/h	6145.9	6145.9		206.6	6350.3	2.3	6350.3
Enthalpy kJ/h	-1.202E+07	-1.018E+07	1.847E+06	2.034E+05	-9.973E+06	1.574E+03	-9.973E+06
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2007
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	341.155	341.155		11.469	352.498	0.126	352.498
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	341.155	341.155		11.469	352.498	0.126	352.498

TABLE 21
(Page 3 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	352.50		352.50			0.38	352.12
Mass Flow kg/h	6350.3		6350.3			6.8	6343.5
Enthalpy kJ/h	-9.961E+06	1.249E+04	-8.864E+06	1.097E+06	1.397E+07	-8.494E+03	5.117E+06
Density kg/m3	944.6234		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	352.498		352.498			0.378	352.121
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	352.498		352.498			0.378	352.121

TABLE 21
(Page 4 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	288	543		543
Pressure kPa	896		896	86	621		621
Molar Flow kgmole/h	352.12		340.65	2202.73	2202.73		0.99
Mass Flow kg/h	6343.5		6136.9	63408.4	63408.4		28.4
Enthalpy kJ/h	6.246E+06	1.129E+06	6.043E+06	1.846E+07	3.509E+07	1.662E+07	1.574E+04
Density kg/m3	3.7298		3.7298	1.0363	3.9504		3.9504
Mole Wt.	18.0151		18.0151	28.7863	28.7863		28.7863
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0147	1.0548		1.0548
Therm Cond W/m-K	0.0404		0.0404	0.0251	0.0414		0.0414
Viscosity cP	0.0186		0.0186	0.0182	0.0289		0.0289
Z Factor	0.9716		0.9716	0.9993	1.0017		1.0017
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	6.608	6.608		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	352.121		340.651	22.027	22.027		0.010
N2	0.000		0.000	1718.128	1718.128		0.771
O2	0.000		0.000	455.965	455.965		0.205
TOTAL, kg-mol/h	352.121		340.651	2202.728	2202.728		0.988

TABLE 21
(Page 5 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	543	978	978	670		656	644
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	722.39	2677.41	2677.41	2677.41		2677.41	2677.41
Mass Flow kg/h	20794.9	71802.7	71802.7	71802.7		71802.7	71802.7
Enthalpy kJ/h	1.151E+07	8.413E+07	8.413E+07	5.573E+07	2.840E+07	5.452E+07	5.339E+07
Density kg/m3	3.9504	1.9859	1.9561	0.5044		0.5116	0.5183
Mole Wt.	28.7863	26.818	26.818	26.818		26.818	26.818
Spec. Heat kJ/kg-C	1.0548	1.3355	1.3355	1.2379		1.2336	1.2296
Therm Cond W/m-K	0.0414	0.0693	0.0693	0.0492		0.0483	0.0474
Viscosity cP	0.0289	0.0388	0.0388	0.0293		0.0289	0.0285
Z Factor	1.0017	1.0012	1.0012	1.0001		1.0001	1.0001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	2.167	137.963	137.963	137.963		137.963	137.963
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	7.224	619.980	619.980	619.980		619.980	619.980
N2	563.462	1720.832	1720.832	1720.832		1720.832	1720.832
O2	149.534	198.635	198.635	198.635		198.635	198.635
TOTAL, kg-mol/h	722.387	2677.409	2677.409	2677.409		2677.409	2677.409

TABLE 21
(Page 6 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	482	469	447	978	978	838	802
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2677.41	2677.41	2677.41	17.23	17.23	26.69	30.41
Mass Flow kg/h	71802.7	71802.7	71802.7	511.4	511.4	681.9	744.6
Enthalpy kJ/h	3.942E+07	3.832E+07	3.647E+07	6.493E+05	6.493E+05	8.171E+05	9.061E+05
Density kg/m3	0.6875	0.7018	0.7312	2.1832	2.1832	2.2301	2.2309
Mole Wt.	26.818	26.818	26.818	29.6879	29.6881	25.5493	24.4832
Spec. Heat kJ/kg-C	1.1823	1.179	1.1735	1.5613	1.5613	1.676	1.8317
Therm Cond W/m-K	0.0364	0.0355	0.034	0.0796	0.0796	0.0697	0.0726
Viscosity cP	0.0231	0.0227	0.0218	0.0367	0.0367	0.0292	0.0279
Z Factor	0.9996	0.9995	0.9993	1.0001	1.0001	0.9982	0.9985
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.030	0.030	0.030	3.605
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.412	0.412	0.412	0.412
CO2	137.963	137.963	137.963	7.953	7.953	7.953	8.028
H2	0.000	0.000	0.000	0.633	0.633	0.633	0.633
H2O	619.980	619.980	619.980	8.158	8.157	17.620	17.620
N2	1720.832	1720.832	1720.832	0.040	0.040	0.040	0.114
O2	198.635	198.635	198.635	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2677.409	2677.409	2677.409	17.226	17.226	26.689	30.412

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	921	800	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	30.41	32.19	37.45		37.45		49.55
Mass Flow kg/h	744.6	744.6	744.6		744.6		1471.2
Enthalpy kJ/h	1.072E+06	9.297E+05	1.380E+06	1.023E+06	1.215E+06	1.797E+06	1.868E+06
Density kg/m3	1.9302	2.0984	1.3575		1.5079		2.1832
Mole Wt.	24.4832	23.1336	19.884		19.8842		29.6881
Spec. Heat kJ/kg-C	1.9115	1.8599	2.0255		1.9746		1.5613
Therm Cond W/m-K	0.0845	0.0847	0.1313		0.1201		0.0796
Viscosity cP	0.0319	0.0285	0.0338		0.0312		0.0367
Z Factor	0.9995	0.9991	1.0007		1.0005		1.0001
Component Flow, kg-mol/h							
CH4	3.605	2.718	0.088		0.088		0.088
C2H6							
C3H8							
n-C4H10							
CO	0.412	0.556	4.699		4.700		1.186
CO2	8.028	8.771	7.258		7.258		22.880
H2	0.633	4.038	10.414		10.414		1.821
H2O	17.620	15.990	14.873		14.873		23.466
N2	0.114	0.114	0.114		0.114		0.114
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	30.412	32.186	37.446		37.446		49.554

TABLE 21
(Page 8 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	32.33	227.19	227.19	110.46	116.73	150.05	149.07
Mass Flow kg/h	959.8	6092.8	6092.8	2962.3	3130.5	4118.7	4118.7
Enthalpy kJ/h	1.218E+06	7.139E+06	7.139E+06	3.471E+06	3.668E+06	4.902E+06	5.449E+06
Density kg/m3	2.1832	1.9859	1.9859	1.9859	1.9859	2.0217	1.849
Mole Wt.	29.6881	26.818	26.818	26.818	26.818	27.4493	27.6299
Spec. Heat kJ/kg-C	1.5613	1.3355	1.3355	1.3355	1.3355	1.386	1.4141
Therm Cond W/m-K	0.0796	0.0693	0.0693	0.0693	0.0693	0.0713	0.076
Viscosity cP	0.0367	0.0388	0.0388	0.0388	0.0388	0.0377	0.0405
Z Factor	1.0001	1.0012	1.0012	1.0012	1.0012	1.001	1.001
Component Flow, kg-mol/h							
CH4	0.057	0.000	0.000	0.000	0.000	0.057	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.773	0.000	0.000	0.000	0.000	0.773	0.000
CO2	14.926	11.707	11.707	5.692	6.015	20.944	21.775
H2	1.188	0.000	0.000	0.000	0.000	1.188	0.000
H2O	15.309	52.607	52.608	25.578	27.030	42.348	43.650
N2	0.074	146.021	146.021	70.995	75.026	75.871	75.871
O2	0.000	16.856	16.855	8.195	8.660	8.865	7.770
TOTAL, kg-mol/h	32.328	227.191	227.191	110.460	116.731	150.047	149.066

TABLE 21
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 15°C AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	893	928	864	867		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	149.07	259.53	3836.70	3836.70		301.56	74.37
Mass Flow kg/h	4118.7	7081.0	105766.8	105766.8		8087.3	1994.5
Enthalpy kJ/h	4.425E+06	7.897E+06	1.063E+08	1.066E+08	3.842E+05	9.476E+06	2.337E+06
Density kg/m3	2.2181	2.1075	2.2869	2.3031		1.9859	1.9859
Mole Wt.	27.6299	27.2843	27.5671	27.5671		26.818	26.818
Spec. Heat kJ/kg-C	1.3577	1.3491	1.2889	1.2898		1.3355	1.3355
Therm Cond W/m-K	0.065	0.0668	0.0622	0.0623		0.0693	0.0693
Viscosity cP	0.0353	0.0366	0.0356	0.0357		0.0388	0.0388
Z Factor	1.0009	1.001	1.0011	1.0012		1.0012	1.0012
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	21.775	27.466	331.762	331.762		15.539	3.832
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	43.650	69.228	837.958	837.958		69.830	17.222
N2	75.871	146.866	2325.859	2325.859		193.822	47.801
O2	7.770	15.965	341.119	341.119		22.373	5.518
TOTAL, kg-mol/h	149.066	259.526	3836.698	3836.698		301.563	74.372

TABLE 22
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 22
(Page 2 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	297.61	297.61		10.02	307.50	0.13	307.50
Mass Flow kg/h	5361.5	5361.5		180.5	5539.7	2.3	5539.7
Enthalpy kJ/h	-1.049E+07	-8.876E+06	1.611E+06	1.777E+05	-8.700E+06	1.580E+03	-8.700E+06
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2007
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	297.610	297.610		10.019	307.503	0.126	307.503
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	297.610	297.610		10.019	307.503	0.126	307.503

TABLE 22
(Page 3 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	307.50		307.50			0.38	307.13
Mass Flow kg/h	5539.7		5539.7			6.8	5532.9
Enthalpy kJ/h	-8.689E+06	1.089E+04	-7.732E+06	9.569E+05	1.219E+07	-8.494E+03	4.463E+06
Density kg/m3	944.6234		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	307.503		307.503			0.378	307.125
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	307.503		307.503			0.378	307.125

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	244	463		463
Pressure kPa	896		896	86	621		621
Molar Flow kgmole/h	307.13		297.11	1926.24	1926.24		0.99
Mass Flow kg/h	5532.9		5352.4	55659.1	55659.1		28.5
Enthalpy kJ/h	5.448E+06	9.847E+05	5.270E+06	1.366E+07	2.600E+07	1.234E+07	1.334E+04
Density kg/m3	3.7298		3.7298	1.2278	4.6519		4.6519
Mole Wt.	18.0151		18.0151	28.8951	28.8951		28.8951
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0079	1.0344		1.0344
Therm Cond W/m-K	0.0404		0.0404	0.022	0.0366		0.0366
Viscosity cP	0.0186		0.0186	0.016	0.0259		0.0259
Z Factor	0.9716		0.9716	0.9987	1.0013		1.0013
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	5.837	5.837		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	307.125		297.106	0.000	0.000		0.000
N2	0.000		0.000	1517.647	1517.647		0.778
O2	0.000		0.000	402.760	402.760		0.207
TOTAL, kg-mol/h	307.125		297.106	1926.244	1926.244		0.988

TABLE 22
(Page 5 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	463	978	978	671		656	643
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	630.23	2357.39	2357.39	2357.39		2357.39	2357.39
Mass Flow kg/h	18210.4	63268.6	63268.6	63268.6		63268.6	63268.6
Enthalpy kJ/h	8.508E+06	7.428E+07	7.428E+07	4.926E+07	2.503E+07	4.804E+07	4.706E+07
Density kg/m3	4.6519	1.9874	1.9576	0.5041		0.5126	0.5192
Mole Wt.	28.8951	26.8384	26.8384	26.8384		26.8384	26.8384
Spec. Heat kJ/kg-C	1.0344	1.3398	1.3398	1.2416		1.2366	1.2326
Therm Cond W/m-K	0.0366	0.0693	0.0693	0.0492		0.0482	0.0473
Viscosity cP	0.0259	0.0386	0.0386	0.0292		0.0287	0.0284
Z Factor	1.0013	1.0012	1.0012	1.0001		1.0001	1.0001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	1.910	137.192	137.192	137.192		137.192	137.192
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	0.000	554.450	554.450	554.450		554.450	554.450
N2	496.541	1520.333	1520.333	1520.333		1520.333	1520.333
O2	131.774	145.413	145.413	145.413		145.413	145.413
TOTAL, kg-mol/h	630.225	2357.388	2357.388	2357.388		2357.388	2357.388

TABLE 22
(Page 6 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	484	471	449	978	978	851	812
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2357.39	2357.39	2357.39	17.26	17.26	25.51	29.23
Mass Flow kg/h	63268.6	63268.6	63268.6	520.4	520.4	669.0	731.8
Enthalpy kJ/h	3.487E+07	3.392E+07	3.231E+07	6.523E+05	6.523E+05	7.987E+05	8.877E+05
Density kg/m3	0.6861	0.7	0.7288	2.2173	2.2173	2.2527	2.2522
Mole Wt.	26.8384	26.8384	26.8384	30.1547	30.1547	26.2273	25.0319
Spec. Heat kJ/kg-C	1.1855	1.1821	1.1766	1.5441	1.5441	1.6501	1.8124
Therm Cond W/m-K	0.0364	0.0355	0.034	0.0792	0.0792	0.0706	0.0736
Viscosity cP	0.0231	0.0226	0.0218	0.0369	0.0369	0.0302	0.0287
Z Factor	0.9996	0.9995	0.9993	1.0002	1.0002	0.9985	0.9987
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.035	0.035	0.035	3.610
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.443	0.443	0.443	0.443
CO2	137.192	137.192	137.192	8.263	8.263	8.263	8.338
H2	0.000	0.000	0.000	0.630	0.630	0.630	0.630
H2O	554.450	554.450	554.450	7.844	7.844	16.097	16.097
N2	1520.333	1520.333	1520.333	0.041	0.041	0.041	0.116
O2	145.413	145.413	145.413	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2357.388	2357.388	2357.388	17.257	17.257	25.510	29.233

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	930	805	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	29.23	30.99	36.25		36.25		48.36
Mass Flow kg/h	731.8	731.8	731.8		731.8		1458.3
Enthalpy kJ/h	1.048E+06	9.053E+05	1.336E+06	1.012E+06	1.175E+06	1.797E+06	1.828E+06
Density kg/m3	1.9531	2.1265	1.3779		1.5306		2.2173
Mole Wt.	25.0319	23.6139	20.1843		20.1843		30.1547
Spec. Heat kJ/kg-C	1.8905	1.8367	1.9948		1.9448		1.5441
Therm Cond W/m-K	0.0853	0.0853	0.1308		0.1197		0.0792
Viscosity cP	0.0324	0.0289	0.0341		0.0315		0.0369
Z Factor	0.9997	0.9993	1.0007		1.0005		1.0002
Component Flow, kg-mol/h							
CH4	3.610	2.732	0.099		0.099		0.099
C2H6							
C3H8							
n-C4H10							
CO	0.443	0.639	5.001		5.001		1.242
CO2	8.338	9.020	7.290		7.290		23.157
H2	0.630	3.945	10.114		10.114		1.765
H2O	16.097	14.537	13.634		13.634		21.983
N2	0.116	0.116	0.116		0.116		0.116
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	29.233	30.988	36.254		36.254		48.362

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	31.10	237.42	237.42	120.64	116.78	148.87	147.91
Mass Flow kg/h	938.0	6372.0	6372.0	3237.8	3134.2	4100.7	4100.7
Enthalpy kJ/h	1.176E+06	7.482E+06	7.482E+06	3.802E+06	3.680E+06	4.869E+06	5.416E+06
Density kg/m3	2.2173	1.9874	1.9874	1.9874	1.9874	2.0296	1.8553
Mole Wt.	30.1547	26.8384	26.8384	26.8384	26.8384	27.545	27.725
Spec. Heat kJ/kg-C	1.5441	1.3398	1.3398	1.3398	1.3398	1.3842	1.4127
Therm Cond W/m-K	0.0792	0.0693	0.0693	0.0693	0.0693	0.0712	0.0759
Viscosity cP	0.0369	0.0386	0.0386	0.0386	0.0386	0.0378	0.0405
Z Factor	1.0002	1.0012	1.0012	1.0012	1.0012	1.001	1.001
Component Flow, kg-mol/h							
CH4	0.064	0.000	0.000	0.000	0.000	0.064	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.799	0.000	0.000	0.000	0.000	0.799	0.000
CO2	14.894	13.817	13.817	7.021	6.796	21.693	22.556
H2	1.135	0.000	0.000	0.000	0.000	1.135	0.000
H2O	14.139	55.841	55.841	28.374	27.466	41.605	42.868
N2	0.074	153.119	153.119	77.804	75.315	76.168	76.168
O2	0.000	14.645	14.645	7.442	7.204	7.410	6.315
TOTAL, kg-mol/h	31.105	237.422	237.422	120.641	116.781	148.874	147.907

TABLE 22
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / -20°C AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	894	930	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	147.91	268.55	3852.79	3852.79		302.90	65.48
Mass Flow kg/h	4100.7	7338.5	106272.8	106272.8		8129.5	1757.5
Enthalpy kJ/h	4.403E+06	8.205E+06	1.070E+08	1.074E+08	3.859E+05	9.545E+06	2.063E+06
Density kg/m3	2.2232	2.1049	2.2883	2.3046		1.9874	1.9874
Mole Wt.	27.725	27.3267	27.5833	27.5833		26.8384	26.8384
Spec. Heat kJ/kg-C	1.3564	1.3497	1.2926	1.2935		1.3398	1.3398
Therm Cond W/m-K	0.065	0.0669	0.0621	0.0623		0.0693	0.0693
Viscosity cP	0.0354	0.0367	0.0355	0.0356		0.0386	0.0386
Z Factor	1.0009	1.001	1.0011	1.0011		1.0012	1.0012
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	22.556	29.577	356.830	356.830		17.628	3.811
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	42.868	71.242	854.906	854.906		71.242	15.401
N2	76.168	153.972	2344.201	2344.201		195.350	42.231
O2	6.315	13.757	296.859	296.859		18.684	4.039
TOTAL, kg-mol/h	147.907	268.547	3852.795	3852.795		302.905	65.483

TABLE 23
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	376.99	376.99		12.66	389.53	0.13	389.53
Mass Flow kg/h	6791.5	6791.5		228.1	7017.3	2.3	7017.3
Enthalpy kJ/h	-1.328E+07	-1.124E+07	2.041E+06	2.246E+05	-1.102E+07	1.569E+03	-1.102E+07
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.201
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	376.989	376.989		12.662	389.525	0.126	389.525
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	376.989	376.989		12.662	389.525	0.126	389.525

TABLE 23
(Page 3 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	389.53		389.53			0.38	389.15
Mass Flow kg/h	7017.3		7017.3			6.8	7010.5
Enthalpy kJ/h	-1.101E+07	1.380E+04	-9.795E+06	1.212E+06	1.544E+07	-8.494E+03	5.655E+06
Density kg/m3	944.6237		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	389.525		389.525			0.378	389.148
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	389.525		389.525			0.378	389.148

TABLE 23
(Page 4 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	322	605		605
Pressure kPa	896		896	86	621		621
Molar Flow kgmole/h	389.15		376.49	2504.67	2504.67		0.99
Mass Flow kg/h	7010.5		6782.4	72372.7	72372.7		28.5
Enthalpy kJ/h	6.903E+06	1.248E+06	6.678E+06	2.344E+07	4.455E+07	2.111E+07	1.757E+04
Density kg/m3	3.7298		3.7298	0.9303	3.5597		3.5597
Mole Wt.	18.0151		18.0151	28.8951	28.8951		28.8951
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0116	1.0616		1.0616
Therm Cond W/m-K	0.0404		0.0404	0.0275	0.045		0.045
Viscosity cP	0.0186		0.0186	0.0199	0.0315		0.0315
Z Factor	0.9716		0.9716	0.9997	1.0019		1.0019
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	7.590	7.590		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	389.148		376.486	0.000	0.000		0.000
N2	0.000		0.000	1973.376	1973.376		0.778
O2	0.000		0.000	523.704	523.704		0.207
TOTAL, kg-mol/h	389.148		376.486	2504.670	2504.670		0.988

TABLE 23
(Page 5 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	605	978	978	668		656	643
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	823.03	3015.11	3015.11	3015.11		3015.11	3015.11
Mass Flow kg/h	23781.7	81409.7	81409.7	81409.7		81409.7	81409.7
Enthalpy kJ/h	1.464E+07	9.423E+07	9.423E+07	6.229E+07	3.194E+07	6.108E+07	5.983E+07
Density kg/m3	3.5597	1.9993	1.9693	0.5092		0.5153	0.5219
Mole Wt.	28.8951	27.0006	27.0006	27.0006		27.0006	27.0006
Spec. Heat kJ/kg-C	1.0616	1.3166	1.3166	1.2212		1.2174	1.2136
Therm Cond W/m-K	0.045	0.069	0.069	0.0491		0.0482	0.0474
Viscosity cP	0.0315	0.0393	0.0393	0.0295		0.0292	0.0288
Z Factor	1.0019	1.0012	1.0012	1.0001		1.0001	1.0001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	2.494	138.949	138.949	138.949		138.949	138.949
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	0.000	633.851	633.851	633.851		633.851	633.851
N2	648.451	1975.985	1975.985	1975.985		1975.985	1975.985
O2	172.089	266.326	266.326	266.326		266.326	266.326
TOTAL, kg-mol/h	823.034	3015.111	3015.111	3015.111		3015.111	3015.111

TABLE 23
(Page 6 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	484	471	450	978	978	838	806
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	3015.11	3015.11	3015.11	19.28	19.28	29.74	33.46
Mass Flow kg/h	81409.7	81409.7	81409.7	565.2	565.2	753.6	816.3
Enthalpy kJ/h	4.439E+07	4.318E+07	4.114E+07	7.248E+05	7.248E+05	9.104E+05	9.993E+05
Density kg/m3	0.6893	0.7033	0.7321	2.1559	2.1559	2.2099	2.2127
Mole Wt.	27.0006	27.0006	27.0006	29.3156	29.3156	25.3415	24.3957
Spec. Heat kJ/kg-C	1.1682	1.165	1.1597	1.575	1.575	1.6864	1.8282
Therm Cond W/m-K	0.0366	0.0358	0.0343	0.08	0.08	0.07	0.0726
Viscosity cP	0.0235	0.023	0.0222	0.0365	0.0365	0.029	0.028
Z Factor	0.9996	0.9996	0.9994	1	1	0.9982	0.9984
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.025	0.025	0.025	3.600
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.443	0.443	0.443	0.443
CO2	138.949	138.949	138.949	8.641	8.641	8.641	8.715
H2	0.000	0.000	0.000	0.722	0.722	0.722	0.722
H2O	633.851	633.851	633.851	9.406	9.406	19.864	19.864
N2	1975.985	1975.985	1975.985	0.043	0.043	0.043	0.118
O2	266.326	266.326	266.326	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	3015.111	3015.111	3015.111	19.280	19.280	29.738	33.461

TABLE 23
(Page 7 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	924	802	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	33.46	35.41	40.52		40.52		52.63
Mass Flow kg/h	816.3	816.3	816.3		816.3		1542.9
Enthalpy kJ/h	1.180E+06	1.024E+06	1.503E+06	1.036E+06	1.322E+06	1.797E+06	1.979E+06
Density kg/m3	1.9164	2.0844	1.3753		1.5278		2.1559
Mole Wt.	24.3957	23.0506	20.1447		20.1447		29.3156
Spec. Heat kJ/kg-C	1.9058	1.8555	2.0147		1.9638		1.575
Therm Cond W/m-K	0.0843	0.0846	0.1284		0.1174		0.08
Viscosity cP	0.032	0.0286	0.0339		0.0313		0.0365
Z Factor	0.9995	0.999	1.0006		1.0004		1
Component Flow, kg-mol/h							
CH4	3.600	2.623	0.069		0.069		0.069
C2H6							
C3H8							
n-C4H10							
CO	0.443	0.602	4.649		4.649		1.209
CO2	8.715	9.532	8.039		8.039		23.588
H2	0.722	4.468	10.638		10.638		1.971
H2O	19.864	18.071	17.009		17.009		25.677
N2	0.118	0.118	0.118		0.118		0.118
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	33.461	35.414	40.522		40.522		52.630

TABLE 23
(Page 8 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	976	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	33.35	218.31	218.31	100.69	117.61	151.95	150.94
Mass Flow kg/h	977.7	5894.4	5894.4	2718.8	3175.6	4181.8	4181.8
Enthalpy kJ/h	1.254E+06	6.823E+06	6.823E+06	3.147E+06	3.676E+06	4.947E+06	5.496E+06
Density kg/m3	2.1559	1.9993	1.9993	1.9993	1.9993	2.0262	1.8539
Mole Wt.	29.3156	27.0005	27.0006	27.0005	27.0005	27.521	27.7046
Spec. Heat kJ/kg-C	1.575	1.3166	1.3166	1.3166	1.3166	1.3751	1.4025
Therm Cond W/m-K	0.08	0.069	0.069	0.069	0.069	0.0712	0.0758
Viscosity cP	0.0365	0.0393	0.0393	0.0393	0.0393	0.038	0.0408
Z Factor	1	1.0012	1.0012	1.0012	1.0012	1.001	1.0011
Component Flow, kg-mol/h							
CH4	0.044	0.000	0.000	0.000	0.000	0.044	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.766	0.000	0.000	0.000	0.000	0.766	0.000
CO2	14.947	10.061	10.061	4.640	5.420	20.370	21.180
H2	1.249	0.000	0.000	0.000	0.000	1.249	0.000
H2O	16.271	45.894	45.894	21.169	24.725	40.996	42.332
N2	0.074	143.068	143.070	65.990	77.078	77.931	77.931
O2	0.000	19.283	19.283	8.894	10.388	10.595	9.500
TOTAL, kg-mol/h	33.350	218.306	218.308	100.694	117.612	151.950	150.943

TABLE 23
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	892	925	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	150.94	251.64	3842.67	3842.67		302.06	83.75
Mass Flow kg/h	4181.8	6900.6	106588.8	106588.8		8155.8	2261.4
Enthalpy kJ/h	4.459E+06	7.606E+06	1.059E+08	1.063E+08	3.850E+05	9.441E+06	2.618E+06
Density kg/m3	2.2264	2.1245	2.301	2.3173		1.9993	1.9993
Mole Wt.	27.7046	27.4229	27.7382	27.7382		27.0006	27.0006
Spec. Heat kJ/kg-C	1.3467	1.3355	1.2725	1.2734		1.3166	1.3166
Therm Cond W/m-K	0.0648	0.0665	0.0619	0.0621		0.069	0.069
Viscosity cP	0.0355	0.0368	0.036	0.0361		0.0393	0.0393
Z Factor	1.0009	1.0011	1.0012	1.0012		1.0012	1.0012
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	21.180	25.820	312.337	312.337		13.920	3.860
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	42.332	63.501	762.008	762.008		63.501	17.607
N2	77.931	143.921	2375.506	2375.506		197.959	54.888
O2	9.500	18.394	392.821	392.821		26.681	7.398
TOTAL, kg-mol/h	150.943	251.636	3842.672	3842.672		302.061	83.753

TABLE 24
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 24
(Page 2 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	383.79	383.79		12.89	396.56	0.13	396.56
Mass Flow kg/h	6914.1	6914.1		232.2	7144.0	2.3	7144.0
Enthalpy kJ/h	-1.352E+07	-1.145E+07	2.078E+06	2.286E+05	-1.122E+07	1.571E+03	-1.122E+07
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.201
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	383.793	383.793		12.888	396.556	0.126	396.556
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	383.793	383.793		12.888	396.556	0.126	396.556

TABLE 24
(Page 3 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	396.56		396.56			0.38	396.18
Mass Flow kg/h	7144.0		7144.0			6.8	7137.2
Enthalpy kJ/h	-1.121E+07	1.405E+04	-9.972E+06	1.234E+06	1.572E+07	-8.494E+03	5.758E+06
Density kg/m3	944.6237		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	396.556		396.556			0.378	396.178
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	396.556		396.556			0.378	396.178

TABLE 24
(Page 4 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	322	598		598
Pressure kPa	896		896	86	621		621
Molar Flow kgmole/h	396.18		383.29	2388.71	2388.71		0.99
Mass Flow kg/h	7137.2		6905.0	66028.4	66028.4		27.3
Enthalpy kJ/h	7.028E+06	1.270E+06	6.799E+06	2.271E+07	4.271E+07	2.001E+07	1.767E+04
Density kg/m3	3.7298		3.7298	0.8908	3.4474		3.4474
Mole Wt.	18.0151		18.0151	27.6418	27.6418		27.6418
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0773	1.1339		1.1339
Therm Cond W/m-K	0.0404		0.0404	0.0267	0.0448		0.0448
Viscosity cP	0.0186		0.0186	0.0182	0.0289		0.0289
Z Factor	0.9716		0.9716	0.9988	1.0011		1.0011
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	6.405	6.405		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	396.178		383.290	275.160	275.160		0.114
N2	0.000		0.000	1665.224	1665.224		0.689
O2	0.000		0.000	441.925	441.925		0.183
TOTAL, kg-mol/h	396.178		383.290	2388.714	2388.714		0.988

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	598	978	978	674		662	649
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	784.38	2906.04	2906.04	2906.04		2906.04	2906.04
Mass Flow kg/h	21681.8	75190.7	75190.7	75190.7		75190.7	75190.7
Enthalpy kJ/h	1.403E+07	9.250E+07	9.250E+07	6.158E+07	3.092E+07	6.037E+07	5.910E+07
Density kg/m3	3.4474	1.9164	1.8877	0.4839		0.4898	0.4963
Mole Wt.	27.6418	25.8739	25.8739	25.8739		25.8739	25.8739
Spec. Heat kJ/kg-C	1.1339	1.4077	1.4077	1.3029		1.2986	1.2942
Therm Cond W/m-K	0.0448	0.0708	0.0708	0.05		0.0491	0.0481
Viscosity cP	0.0289	0.0371	0.0371	0.0284		0.028	0.0276
Z Factor	1.0011	1.001	1.001	1		1	0.9999
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	2.103	137.770	137.770	137.770		137.770	137.770
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	90.354	915.799	915.799	915.799		915.799	915.799
N2	546.810	1667.905	1667.905	1667.905		1667.905	1667.905
O2	145.115	184.569	184.569	184.569		184.569	184.569
TOTAL, kg-mol/h	784.382	2906.043	2906.043	2906.043		2906.043	2906.043

TABLE 24
(Page 6 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	484	470	448	978	978	839	807
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2906.04	2906.04	2906.04	19.67	19.67	30.32	34.04
Mass Flow kg/h	75190.7	75190.7	75190.7	575.4	575.4	767.2	829.9
Enthalpy kJ/h	4.338E+07	4.214E+07	4.007E+07	7.393E+05	7.393E+05	9.282E+05	1.017E+06
Density kg/m3	0.6617	0.6758	0.7049	2.151	2.151	2.2062	2.2094
Mole Wt.	25.8739	25.8739	25.8739	29.2483	29.2483	25.3038	24.3783
Spec. Heat kJ/kg-C	1.2414	1.2377	1.2316	1.5775	1.5775	1.6883	1.8277
Therm Cond W/m-K	0.0362	0.0353	0.0337	0.08	0.08	0.07	0.0726
Viscosity cP	0.022	0.0214	0.0205	0.0365	0.0365	0.029	0.028
Z Factor	0.9993	0.9992	0.999	1	1	0.9982	0.9984
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.024	0.024	0.024	3.599
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.448	0.448	0.448	0.448
CO2	137.770	137.770	137.770	8.769	8.769	8.769	8.843
H2	0.000	0.000	0.000	0.739	0.739	0.739	0.739
H2O	915.799	915.799	915.799	9.650	9.650	20.297	20.297
N2	1667.905	1667.905	1667.905	0.044	0.044	0.044	0.118
O2	184.569	184.569	184.569	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2906.043	2906.043	2906.043	19.674	19.674	30.320	34.044

TABLE 24
(Page 7 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	925	803	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	34.04	36.03	41.11		41.11		53.22
Mass Flow kg/h	829.9	829.9	829.9		829.9		1556.5
Enthalpy kJ/h	1.200E+06	1.041E+06	1.526E+06	1.039E+06	1.343E+06	1.797E+06	2.000E+06
Density kg/m3	1.9138	2.0818	1.3783		1.5311		2.151
Mole Wt.	24.3783	23.0342	20.1885		20.1885		29.2483
Spec. Heat kJ/kg-C	1.905	1.8549	2.013		1.962		1.5775
Therm Cond W/m-K	0.0843	0.0846	0.1278		0.1169		0.08
Viscosity cP	0.032	0.0286	0.0339		0.0313		0.0365
Z Factor	0.9994	0.999	1.0006		1.0004		1
Component Flow, kg-mol/h							
CH4	3.599	2.605	0.066		0.066		0.066
C2H6							
C3H8							
n-C4H10							
CO	0.448	0.611	4.639		4.639		1.212
CO2	8.843	9.674	8.185		8.185		23.720
H2	0.739	4.549	10.679		10.679		1.998
H2O	20.297	18.473	17.422		17.422		26.103
N2	0.118	0.118	0.118		0.118		0.118
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	34.044	36.030	41.109		41.109		53.217

TABLE 24
(Page 8 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	33.54	213.99	213.99	99.48	114.51	149.05	148.03
Mass Flow kg/h	981.1	5536.9	5536.9	2573.9	2962.9	3971.3	3971.3
Enthalpy kJ/h	1.261E+06	6.811E+06	6.811E+06	3.166E+06	3.645E+06	4.923E+06	5.472E+06
Density kg/m3	2.151	1.9164	1.9164	1.9164	1.9164	1.9624	1.7955
Mole Wt.	29.2483	25.8739	25.8739	25.8739	25.8739	26.645	26.8271
Spec. Heat kJ/kg-C	1.5775	1.4077	1.4077	1.4077	1.4077	1.4477	1.4775
Therm Cond W/m-K	0.08	0.0708	0.0708	0.0708	0.0708	0.0727	0.0774
Viscosity cP	0.0365	0.0371	0.0371	0.0371	0.0371	0.0367	0.0393
Z Factor	1	1.001	1.001	1.001	1.001	1.0008	1.0009
Component Flow, kg-mol/h							
CH4	0.042	0.000	0.000	0.000	0.000	0.042	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.764	0.000	0.000	0.000	0.000	0.764	0.000
CO2	14.951	10.145	10.145	4.716	5.429	20.383	21.188
H2	1.259	0.000	0.000	0.000	0.000	1.259	0.000
H2O	16.453	67.437	67.437	31.350	36.088	52.655	53.997
N2	0.074	122.821	122.821	57.096	65.725	66.488	66.488
O2	0.000	13.591	13.591	6.318	7.273	7.456	6.361
TOTAL, kg-mol/h	33.544	213.994	213.994	99.480	114.514	149.046	148.034

TABLE 24
(Page 9 of 9)

FULL-LOAD, START-OF-RUN OPERATION - 5,000' ELEV. / 49°C (100% REL. HUMIDITY) AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	891	925	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	148.03	247.51	3754.55	3754.55		294.72	80.72
Mass Flow kg/h	3971.3	6545.3	100225.0	100225.0		7625.5	2088.6
Enthalpy kJ/h	4.433E+06	7.599E+06	1.052E+08	1.056E+08	3.760E+05	9.381E+06	2.569E+06
Density kg/m3	2.1578	2.0493	2.2151	2.2309		1.9164	1.9164
Mole Wt.	26.8271	26.444	26.6943	26.6943		25.8739	25.8739
Spec. Heat kJ/kg-C	1.4168	1.4139	1.3516	1.3526		1.4077	1.4077
Therm Cond W/m-K	0.066	0.068	0.0633	0.0635		0.0708	0.0708
Viscosity cP	0.0344	0.0354	0.0344	0.0344		0.0371	0.0371
Z Factor	1.0006	1.0008	1.0008	1.0009		1.001	1.001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	21.188	25.905	312.958	312.958		13.972	3.827
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	53.997	85.347	1114.514	1114.514		92.876	25.439
N2	66.488	123.584	2029.817	2029.817		169.151	46.331
O2	6.361	12.679	297.264	297.264		18.718	5.127
TOTAL, kg-mol/h	148.034	247.514	3754.553	3754.553		294.718	80.723

TABLE 25
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 25
(Page 2 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	365.65	365.65		12.28	377.81	0.13	377.81
Mass Flow kg/h	6587.2	6587.2		221.3	6806.2	2.3	6806.2
Enthalpy kJ/h	-1.289E+07	-1.091E+07	1.979E+06	2.179E+05	-1.069E+07	1.573E+03	-1.069E+07
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2007
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	365.649	365.649		12.285	377.808	0.126	377.808
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	365.649	365.649		12.285	377.808	0.126	377.808

TABLE 25
(Page 3 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	377.81		377.81			0.38	377.43
Mass Flow kg/h	6806.2		6806.2			6.8	6799.4
Enthalpy kJ/h	-1.068E+07	1.338E+04	-9.500E+06	1.176E+06	1.498E+07	-8.494E+03	5.485E+06
Density kg/m3	944.6234		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	377.808		377.808			0.378	377.430
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	377.808		377.808			0.378	377.430

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	288	518		518
Pressure kPa	896		896	101	621		621
Molar Flow kgmole/h	377.43		365.15	2399.53	2399.53		0.99
Mass Flow kg/h	6799.4		6578.1	69073.6	69073.6		28.4
Enthalpy kJ/h	6.695E+06	1.210E+06	6.477E+06	2.011E+07	3.640E+07	1.629E+07	1.499E+04
Density kg/m3	3.7298		3.7298	1.2105	4.1419		4.1419
Mole Wt.	18.0151		18.0151	28.7863	28.7863		28.7863
Spec. Heat kJ/kg-C	2.0458		2.0458	1.015	1.0499		1.0499
Therm Cond W/m-K	0.0404		0.0404	0.0251	0.0399		0.0399
Viscosity cP	0.0186		0.0186	0.0182	0.0279		0.0279
Z Factor	0.9716		0.9716	0.9992	1.0016		1.0016
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	7.199	7.199		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	377.430		365.146	23.995	23.995		0.010
N2	0.000		0.000	1871.633	1871.633		0.771
O2	0.000		0.000	496.703	496.703		0.205
TOTAL, kg-mol/h	377.430		365.146	2399.530	2399.530		0.988

TABLE 25
(Page 5 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	518	978	978	669		657	644
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	787.99	2898.71	2898.71	2898.71		2898.71	2898.71
Mass Flow kg/h	22683.3	77908.5	77908.5	77908.5		77908.5	77908.5
Enthalpy kJ/h	1.195E+07	9.085E+07	9.085E+07	6.012E+07	3.073E+07	5.890E+07	5.769E+07
Density kg/m3	4.1419	1.9902	1.9604	0.5062		0.5126	0.5192
Mole Wt.	28.7863	26.877	26.877	26.877		26.877	26.877
Spec. Heat kJ/kg-C	1.0499	1.3276	1.3276	1.231		1.227	1.2231
Therm Cond W/m-K	0.0399	0.0692	0.0692	0.0492		0.0483	0.0475
Viscosity cP	0.0279	0.039	0.039	0.0294		0.029	0.0286
Z Factor	1.0016	1.0012	1.0012	1.0001		1.0001	1.0001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	2.364	138.567	138.567	138.567		138.567	138.567
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	7.880	646.523	646.523	646.523		646.523	646.523
N2	614.630	1874.294	1874.294	1874.294		1874.294	1874.294
O2	163.113	239.327	239.327	239.327		239.327	239.327
TOTAL, kg-mol/h	787.987	2898.710	2898.710	2898.710		2898.710	2898.710

TABLE 25
(Page 6 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	484	471	449	978	978	838	805
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	2898.71	2898.71	2898.71	18.60	18.60	28.74	32.46
Mass Flow kg/h	77908.5	77908.5	77908.5	548.2	548.2	730.9	793.6
Enthalpy kJ/h	4.272E+07	4.154E+07	3.956E+07	7.004E+05	7.004E+05	8.803E+05	9.693E+05
Density kg/m3	0.687	0.7011	0.7301	2.1678	2.1678	2.2185	2.2205
Mole Wt.	26.877	26.877	26.877	29.4773	29.4773	25.432	24.4467
Spec. Heat kJ/kg-C	1.1767	1.1735	1.1681	1.5706	1.5706	1.6829	1.8288
Therm Cond W/m-K	0.0365	0.0357	0.0342	0.0796	0.0796	0.0698	0.0725
Viscosity cP	0.0233	0.0228	0.022	0.0366	0.0366	0.0291	0.0279
Z Factor	0.9996	0.9995	0.9994	1.0001	1.0001	0.9982	0.9984
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.042	0.042	0.042	3.616
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.411	0.411	0.411	0.411
CO2	138.567	138.567	138.567	8.434	8.434	8.434	8.508
H2	0.000	0.000	0.000	0.657	0.657	0.657	0.657
H2O	646.523	646.523	646.523	9.011	9.011	19.154	19.154
N2	1874.294	1874.294	1874.294	0.042	0.042	0.042	0.116
O2	239.327	239.327	239.327	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	2898.710	2898.710	2898.710	18.597	18.597	28.740	32.463

TABLE 25
(Page 7 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	923	801	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	32.46	34.37	39.46		39.46		51.57
Mass Flow kg/h	793.6	793.6	793.6		793.6		1520.2
Enthalpy kJ/h	1.145E+06	9.920E+05	1.463E+06	1.026E+06	1.287E+06	1.663E+06	1.942E+06
Density kg/m3	1.9226	2.0926	1.373		1.5251		2.1678
Mole Wt.	24.4467	23.0915	20.11		20.11		29.4773
Spec. Heat kJ/kg-C	1.9072	1.8558	2.0174		1.9664		1.5706
Therm Cond W/m-K	0.0842	0.0844	0.1289		0.1179		0.0796
Viscosity cP	0.032	0.0285	0.0339		0.0313		0.0366
Z Factor	0.9995	0.999	1.0006		1.0004		1.0001
Component Flow, kg-mol/h							
CH4	3.616	2.663	0.116		0.116		0.116
C2H6							
C3H8							
n-C4H10							
CO	0.411	0.579	4.614		4.614		1.139
CO2	8.508	9.293	7.805		7.805		23.388
H2	0.657	4.300	10.456		10.456		1.823
H2O	19.154	17.417	16.356		16.356		24.989
N2	0.116	0.116	0.116		0.116		0.116
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	32.463	34.368	39.464		39.464		51.571

TABLE 25
(Page 8 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	32.97	255.38	255.38	140.68	114.70	148.66	147.72
Mass Flow kg/h	972.0	6863.9	6863.9	3781.1	3082.8	4083.3	4083.3
Enthalpy kJ/h	1.242E+06	8.004E+06	8.004E+06	4.409E+06	3.595E+06	4.852E+06	5.394E+06
Density kg/m3	2.1678	1.9902	1.9902	1.9902	1.9902	2.0233	1.8498
Mole Wt.	29.4773	26.8769	26.877	26.8769	26.8769	27.4664	27.6425
Spec. Heat kJ/kg-C	1.5706	1.3276	1.3276	1.3276	1.3276	1.3833	1.4113
Therm Cond W/m-K	0.0796	0.0692	0.0692	0.0692	0.0692	0.0713	0.076
Viscosity cP	0.0366	0.039	0.039	0.039	0.039	0.0378	0.0405
Z Factor	1.0001	1.0012	1.0012	1.0012	1.0012	1.001	1.001
Component Flow, kg-mol/h							
CH4	0.074	0.000	0.000	0.000	0.000	0.074	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.729	0.000	0.000	0.000	0.000	0.729	0.000
CO2	14.954	12.208	12.208	6.725	5.483	20.440	21.243
H2	1.165	0.000	0.000	0.000	0.000	1.165	0.000
H2O	15.978	56.961	56.960	31.378	25.583	41.571	42.885
N2	0.074	165.129	165.129	90.963	74.165	75.010	75.010
O2	0.000	21.085	21.085	11.615	9.470	9.674	8.579
TOTAL, kg-mol/h	32.975	255.383	255.383	140.681	114.702	148.664	147.717

TABLE 25
(Page 9 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 15°C AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	890	932	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	147.72	288.40	4248.77	4248.77		335.90	80.52
Mass Flow kg/h	4083.3	7864.3	117055.4	117055.4		9028.0	2164.1
Enthalpy kJ/h	4.367E+06	8.776E+06	1.173E+08	1.177E+08	4.255E+05	1.053E+07	2.524E+06
Density kg/m3	2.2252	2.0974	2.2855	2.3017		1.9902	1.9902
Mole Wt.	27.6425	27.269	27.5504	27.5504		26.877	26.877
Spec. Heat kJ/kg-C	1.3543	1.3422	1.2832	1.2841		1.3276	1.3276
Therm Cond W/m-K	0.0648	0.067	0.0621	0.0623		0.0692	0.0692
Viscosity cP	0.0353	0.0369	0.0358	0.0358		0.039	0.039
Z Factor	1.0009	1.0011	1.0012	1.0012		1.0012	1.0012
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	21.243	27.968	337.979	337.979		16.057	3.849
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	42.885	74.262	899.028	899.028		74.919	17.959
N2	75.010	165.974	2606.316	2606.316		217.193	52.064
O2	8.579	20.194	405.444	405.444		27.733	6.648
TOTAL, kg-mol/h	147.717	288.398	4248.768	4248.768		335.902	80.520

TABLE 26
Stream Summary Information
(Page 1 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Natural Gas Supply	Discharge from Natural Gas Compressor	Natural Gas Compressor GHP	Natural Gas Fuel to Combustor	Natural Gas to Process Unit	Pre-heated Natural Gas	Natural Gas Pre-heater Duty
Temperature K	288	426		426	426	616	
Pressure kPa	200	749		749	749	715	
Molar Flow kgmole/h	134.04	134.04		0.00	134.04	134.04	
Mass Flow kg/h	2257.4	2257.4		0.0	2257.4	2257.4	
Enthalpy kJ/h	1.287E+06	1.990E+06	7.032E+05	0.000E+00	1.990E+06	3.203E+06	1.212E+06
Density kg/m3	1.4125	3.5809		3.5809	3.5809	2.3479	
Mole Wt.	16.8416	16.8416		16.8416	16.8416	16.8416	
Spec. Heat kJ/kg-C	2.1213	2.499		2.499	2.499	3.1371	
Therm Cond W/m-K	0.0317	0.053		0.053	0.053	0.0862	
Viscosity cP	0.0111	0.0154		0.0154	0.0154	0.0201	
Z Factor	0.9951	0.9962		0.9962	0.9962	1.0006	
Component Flow, kg-mol/h							
CH4	128.676	128.676		0.000	128.676	128.676	
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	
CO2	2.681	2.681		0.000	2.681	2.681	
H2	0.000	0.000		0.000	0.000	0.000	
H2O	0.000	0.000		0.000	0.000	0.000	
N2	2.681	2.681		0.000	2.681	2.681	
O2	0.000	0.000		0.000	0.000	0.000	
TOTAL, kg-mol/h	134.038	134.038		0.000	134.038	134.038	

TABLE 26
(Page 2 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Demineralized Feedwater	Pre-heated Feedwater	Demin. Pre-heater Duty	Steam to Deaerator	Boiler Feedwater	Deaerator Vent	BFW Pump Suction
Temperature K	289	358		536	378	378	378
Pressure kPa	276	241		896	119	119	148
Molar Flow kgmole/h	390.50	390.50		13.11	403.49	0.13	403.49
Mass Flow kg/h	7035.0	7035.0		236.2	7268.9	2.3	7268.9
Enthalpy kJ/h	-1.376E+07	-1.165E+07	2.114E+06	2.326E+05	-1.142E+07	1.571E+03	-1.142E+07
Density kg/m3	1014.4741	960.4306		3.7298	944.1871	0.6873	944.2013
Mole Wt.	18.0151	18.0151		18.0151	18.0151	18.0151	18.0151
Spec. Heat kJ/kg-C	4.3154	4.3654		2.0458	4.4086	1.9114	4.4085
Therm Cond W/m-K	0.5963	0.673		0.0404	0.6824	0.0248	0.6824
Viscosity cP	1.1197	0.3301		0.0186	0.2666	0.0122	0.2666
Z Factor	0.002	0.0015		0.9716	0.0007	0.9902	0.0009
Component Flow, kg-mol/h							
CH4	0.000	0.000		0.000	0.000	0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000		0.000	0.000	0.000	0.000
CO2	0.000	0.000		0.000	0.000	0.000	0.000
H2	0.000	0.000		0.000	0.000	0.000	0.000
H2O	390.504	390.504		13.111	403.489	0.126	403.489
N2	0.000	0.000		0.000	0.000	0.000	0.000
O2	0.000	0.000		0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	390.504	390.504		13.111	403.489	0.126	403.489

TABLE 26
(Page 3 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	BFW Pump Discharge	BFW Pump HP	BFW to Steam Drum	BFW Heater Duty	Boiler Duty	Boiler Blowdown	Boiler Steam
Temperature K	378		416			448	448
Pressure kPa	1448		1276			896	896
Molar Flow kgmole/h	403.49		403.49			0.38	403.11
Mass Flow kg/h	7268.9		7268.9			6.8	7262.1
Enthalpy kJ/h	-1.140E+07	1.429E+04	-1.015E+07	1.256E+06	1.600E+07	-8.494E+03	5.858E+06
Density kg/m3	944.624		910.4422			879.3838	4.5488
Mole Wt.	18.0151		18.0151			18.0151	18.0151
Spec. Heat kJ/kg-C	4.4058		4.5373			4.7092	2.0286
Therm Cond W/m-K	0.6825		0.6875			0.6788	0.0308
Viscosity cP	0.266		0.1901			0.1535	0.0148
Z Factor	0.0088		0.0073			0.0049	0.952
Component Flow, kg-mol/h							
CH4	0.000		0.000			0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000			0.000	0.000
CO2	0.000		0.000			0.000	0.000
H2	0.000		0.000			0.000	0.000
H2O	403.489		403.489			0.378	403.112
N2	0.000		0.000			0.000	0.000
O2	0.000		0.000			0.000	0.000
TOTAL, kg-mol/h	403.489		403.489			0.378	403.112

TABLE 26
(Page 4 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Superheated Steam	Superheater Duty	Steam to Process Unit	Ambient Air	Air Compressor Discharge	Air Compressor GHP	Process Air to Combustor
Temperature K	536		536	322	577		577
Pressure kPa	896		896	101	621		621
Molar Flow kgmole/h	403.11		390.00	2709.78	2709.78		0.99
Mass Flow kg/h	7262.1		7025.9	78299.5	78299.5		28.5
Enthalpy kJ/h	7.151E+06	1.292E+06	6.918E+06	2.536E+07	4.591E+07	2.055E+07	1.674E+04
Density kg/m3	3.7298		3.7298	1.0867	3.7303		3.7303
Mole Wt.	18.0151		18.0151	28.8951	28.8951		28.8951
Spec. Heat kJ/kg-C	2.0458		2.0458	1.0118	1.0557		1.0557
Therm Cond W/m-K	0.0404		0.0404	0.0275	0.0434		0.0434
Viscosity cP	0.0186		0.0186	0.0199	0.0304		0.0304
Z Factor	0.9716		0.9716	0.9997	1.0019		1.0019
Component Flow, kg-mol/h							
CH4	0.000		0.000	0.000	0.000		0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000		0.000	0.000	0.000		0.000
CO2	0.000		0.000	8.212	8.212		0.003
H2	0.000		0.000	0.000	0.000		0.000
H2O	403.112		390.000	0.000	0.000		0.000
N2	0.000		0.000	2134.981	2134.981		0.778
O2	0.000		0.000	566.591	566.591		0.207
TOTAL, kg-mol/h	403.112		390.000	2709.784	2709.784		0.988

TABLE 26
(Page 5 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Process Air to Recycle Blower	Turbine Combustor Feed	Turbine Inlet	Turbine Exhaust	Turbine GHP	Flue Gas Exit N.G. Pre-heater	Flue Gas Exit Steam Superheater
Temperature K	577	978	978	667		656	644
Pressure kPa	621	603	594	105		104	103
Molar Flow kgmole/h	891.41	3233.82	3233.82	3233.82		3233.82	3233.82
Mass Flow kg/h	25757.3	87582.5	87582.5	87582.5		87582.5	87582.5
Enthalpy kJ/h	1.510E+07	1.008E+08	1.008E+08	6.656E+07	3.424E+07	6.535E+07	6.406E+07
Density kg/m3	3.7303	2.0054	1.9753	0.5114		0.5169	0.5232
Mole Wt.	28.8951	27.0833	27.0833	27.0833		27.0833	27.0833
Spec. Heat kJ/kg-C	1.0557	1.3077	1.3077	1.2134		1.2099	1.2062
Therm Cond W/m-K	0.0434	0.0688	0.0688	0.049		0.0482	0.0474
Viscosity cP	0.0304	0.0396	0.0396	0.0297		0.0293	0.0289
Z Factor	1.0019	1.0013	1.0013	1.0001		1.0001	1.0001
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	2.701	139.571	139.571	139.571		139.571	139.571
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	0.000	647.351	647.351	647.351		647.351	647.351
N2	702.319	2137.663	2137.663	2137.663		2137.663	2137.663
O2	186.385	309.237	309.237	309.237		309.237	309.237
TOTAL, kg-mol/h	891.405	3233.820	3233.821	3233.821		3233.821	3233.821

TABLE 26
(Page 6 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Flue Gas Exit Steam Boiler	Flue Gas Exit BFW Heater	Flue Gas Exit Demin Feedwater Heater	Anode Recycle Gas	Anode Recycle Gas	Ejector Exit Stream	Exchanger Feed Stream
Temperature K	490	477	456	978	978	839	807
Pressure kPa	103	102	101	598	598	607	607
Molar Flow kgmole/h	3233.82	3233.82	3233.82	20.04	20.04	30.87	34.59
Mass Flow kg/h	87582.5	87582.5	87582.5	585.5	585.5	780.7	843.4
Enthalpy kJ/h	4.806E+07	4.681E+07	4.469E+07	7.532E+05	7.532E+05	9.454E+05	1.034E+06
Density kg/m3	0.6838	0.6968	0.7238	2.149	2.149	2.2045	2.2079
Mole Wt.	27.0833	27.0833	27.0833	29.2217	29.2218	25.2889	24.3797
Spec. Heat kJ/kg-C	1.1627	1.1596	1.1545	1.5799	1.5799	1.69	1.8271
Therm Cond W/m-K	0.0371	0.0362	0.0348	0.0799	0.0799	0.07	0.0725
Viscosity cP	0.0238	0.0234	0.0226	0.0364	0.0364	0.029	0.0279
Z Factor	0.9997	0.9996	0.9995	1	1	0.9981	0.9984
Component Flow, kg-mol/h							
CH_4	0.000	0.000	0.000	0.037	0.037	0.037	3.611
C_2H_6							
C_3H_8							
n-C_4H_{10}							
CO	0.000	0.000	0.000	0.433	0.433	0.433	0.433
CO_2	139.571	139.571	139.571	8.901	8.901	8.901	8.975
H_2	0.000	0.000	0.000	0.721	0.721	0.721	0.721
H_2O	647.351	647.351	647.351	9.899	9.899	20.733	20.733
N_2	2137.663	2137.663	2137.663	0.044	0.044	0.044	0.119
O_2	309.237	309.237	309.237	0.000	0.000	0.000	0.000
TOTAL, kg-mol/h	3233.821	3233.821	3233.821	20.036	20.036	30.869	34.593

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Pre-reformer Feed Stream	Reformer Feed Stream	Reformer Exit	Reformer Process Duty	Anode Feed	MCFC Stack Energy Recovery	Anode Exhaust
Temperature K	925	802	1061		950		978
Pressure kPa	603	603	603		599		598
Molar Flow kgmole/h	34.59	36.62	41.62		41.62		53.72
Mass Flow kg/h	843.4	843.4	843.4		843.4		1569.9
Enthalpy kJ/h	1.220E+06	1.058E+06	1.548E+06	1.036E+06	1.362E+06	1.663E+06	2.020E+06
Density kg/m3	1.9128	2.0825	1.3836		1.537		2.149
Mole Wt.	24.3797	23.0292	20.2648		20.2648		29.2218
Spec. Heat kJ/kg-C	1.9041	1.8536	2.0112		1.9601		1.5799
Therm Cond W/m-K	0.0841	0.0844	0.1271		0.1162		0.0799
Viscosity cP	0.032	0.0286	0.034		0.0314		0.0364
Z Factor	0.9994	0.9989	1.0006		1.0003		1
Component Flow, kg-mol/h							
CH4	3.611	2.597	0.099		0.099		0.099
C2H6							
C3H8							
n-C4H10							
CO	0.433	0.611	4.584		4.584		1.162
CO2	8.975	9.812	8.337		8.337		23.867
H2	0.721	4.601	10.619		10.619		1.934
H2O	20.733	18.882	17.859		17.859		26.544
N2	0.119	0.119	0.119		0.119		0.119
O2	0.000	0.000	0.000		0.000		0.000
TOTAL, kg-mol/h	34.593	36.621	41.617		41.617		53.725

TABLE 26
(Page 8 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Anode Exhaust to Combustor	Cathode Recycle Gas	Cathode Recycle Gas	Cathode Recycle Bypass	Cathode Recycle to Combustor	Combined Feed to Combustor	Combustor Effluent
Temperature K	978	978	978	978	978	975	1072
Pressure kPa	598	603	603	603	603	598	597
Molar Flow kgmole/h	33.69	247.37	247.37	131.43	115.95	150.62	149.65
Mass Flow kg/h	984.4	6699.7	6699.7	3559.5	3140.2	4153.2	4153.2
Enthalpy kJ/h	1.267E+06	7.711E+06	7.711E+06	4.097E+06	3.614E+06	4.897E+06	5.441E+06
Density kg/m3	2.149	2.0054	2.0054	2.0054	2.0054	2.0304	1.8571
Mole Wt.	29.2218	27.0833	27.0833	27.0833	27.0833	27.5735	27.7523
Spec. Heat kJ/kg-C	1.5799	1.3077	1.3077	1.3077	1.3077	1.3703	1.3976
Therm Cond W/m-K	0.0799	0.0688	0.0688	0.0688	0.0688	0.0711	0.0757
Viscosity cP	0.0364	0.0396	0.0396	0.0396	0.0396	0.0381	0.0409
Z Factor	1	1.0013	1.0013	1.0013	1.0013	1.0011	1.0011
Component Flow, kg-mol/h							
CH4	0.062	0.000	0.000	0.000	0.000	0.062	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.728	0.000	0.000	0.000	0.000	0.728	0.000
CO2	14.966	10.677	10.677	5.672	5.004	19.973	20.764
H2	1.213	0.000	0.000	0.000	0.000	1.213	0.000
H2O	16.645	49.520	49.520	26.309	23.210	39.855	41.192
N2	0.074	163.522	163.522	86.877	76.645	77.498	77.498
O2	0.000	23.655	23.655	12.568	11.088	11.294	10.199
TOTAL, kg-mol/h	33.689	247.374	247.374	131.427	115.947	150.624	149.654

TABLE 26
(Page 9 of 9)

FULL-LOAD, END-OF-RUN OPERATION - SEA LEVEL / 49°C (0% REL. HUMIDITY) AMBIENT AIR

Stream Description	Reformer Flue Gas	Power Module Gas to Blower	Recycle Blower Suction	Recycle Blower Discharge	Recycle Blower GHP	Cathode Exhaust Gas	Cathode Exhaust to Expander
Temperature K	890	930	864	866		978	978
Pressure kPa	596	596	596	603		603	603
Molar Flow kgmole/h	149.65	281.08	4264.37	4264.37		337.20	89.83
Mass Flow kg/h	4153.2	7712.7	118309.6	118309.6		9132.5	2432.8
Enthalpy kJ/h	4.405E+06	8.502E+06	1.171E+08	1.176E+08	4.271E+05	1.051E+07	2.800E+06
Density kg/m3	2.2349	2.1149	2.3015	2.3177		2.0054	2.0054
Mole Wt.	27.7523	27.4395	27.7437	27.7437		27.0833	27.0833
Spec. Heat kJ/kg-C	1.3416	1.3267	1.2658	1.2667		1.3077	1.3077
Therm Cond W/m-K	0.0646	0.0666	0.0618	0.062		0.0688	0.0688
Viscosity cP	0.0355	0.0372	0.0362	0.0363		0.0396	0.0396
Z Factor	1.0009	1.0011	1.0012	1.0013		1.0013	1.0013
Component Flow, kg-mol/h							
CH4	0.000	0.000	0.000	0.000		0.000	0.000
C2H6							
C3H8							
n-C4H10							
CO	0.000	0.000	0.000	0.000		0.000	0.000
CO2	20.764	26.436	319.936	319.936		14.554	3.877
H2	0.000	0.000	0.000	0.000		0.000	0.000
H2O	41.192	67.502	810.020	810.020		67.502	17.982
N2	77.498	164.375	2674.823	2674.823		222.902	59.380
O2	10.199	22.767	459.589	459.589		32.245	8.590
TOTAL, kg-mol/h	149.654	281.080	4264.368	4264.368		337.202	89.828

3.B.4. Control Concept

3.B.4.a Fuel Cell

Fuel Cell Stack Temperature Control

The primary temperature control of the fuel cell stack is by adjustment of the balance of plant process controls based upon the outlet temperature of the stack's cathode effluent gas flow. These process control adjustments are the regulation of the amount of natural gas introduced to the plant's fuel cell system to maintain the reformer combustor outlet temperature; regulation of the flow of compressed air introduced upstream of the cathode inlet; and the total recycle gas flow rate through the cathode of the fuel cell stack.

Air from the turbine is mixed with the reformer combustor effluent and is supplied to the inlet of the cathode recycle blower. The cathode recycle blower outlet provides the required cooling gas flow to the cathode inlet of the stack. The total flow supplied to the cathode side of the stack is set to meet the excess air required based upon the natural gas flow rate and the cooling flow demanded for cooling as determined by the cathode effluent temperature.

The anode inlet temperature is controlled by varying the natural gas flow bypassed around the reformer feed/effluent heat exchanger. The anode inlet temperature is monitored to ascertain that the proper amount of anode recycle is used to maintain a safe margin above the critical Boudovard carbon formation temperature.

Stack Clamping

A stack clamping system is required to maintain the correct clamping force on the fuel cell stack. The clamping system consists of a set of springs initially set at the factory and periodically adjusted during plant outages.

Reformer/Fuel Cell Containment Vessel Purge Gas Control

Purge air is used to prevent accumulation of combustible gas mixtures in the reformer/fuel cell containment vessel. The purge air is designed to continuously sweep through the containment vessel to the reformer combustor. The vessel pressure is controlled to be lower than the process fuel streams for the reformer and fuel cell systems. The flow rate of the purge air is adjusted based upon vessel effluent temperature or O_2 and CO_2 concentrations.

Fuel Cell Stack Output Current Control

The inverter used in the plant design will control the current draw from the stack based upon operating stack voltage. The current draw control limits will be based upon the maximum and minimum design limits of the plant. This approach allows stack operation based upon the actual realized stack performance at the most efficient stack operating point. Compensation and adjustment of the plant controls for the slow decline in stack performance, or "decay rate", of the fuel cell stack are based upon the fuel gas flow controls following the operating current of the stack over time and providing an automatic unmanned response. In addition, the heat provided from the stack due to internal losses to the balance of plant is held constant with this control concept for improvements in thermal integration and minimizing the required turndown ratios and inherent inefficiencies of the various pieces of balance of plant equipment.

3.B.4.b Turbine Generator

The information contained below is conceptual in nature and subject to change with further HEFPP design and development work. The Rolls- Royce Allison gas turbine generator will be controlled by a programmable logic control system. The gas turbine generator programmable logic control system (PLC) will be interconnected by Ethernet to the plant distributed control system (DCS) for monitoring purposes only. All safety related interlocks such as start/stop/trip and combustor management system will be hardwired between the PLC and the DCS to avoid the potential signal delays associated with digital networks.

Operating Modes

The gas turbine generator is capable of operating in either island mode or electric grid connected mode on the PLC system. The signal to change from one mode to another will come from the DCS via a hardwired signal based on the position of the plant-to-electric-grid circuit breaker.

The gas turbine generator controls will allow the turbine generator to operate in standalone mode where natural gas is in the combustor (normally in plant startup conditions) or in fuel cell support mode where the fuel cell exhaust is used to drive the gas turbine and no gas is used in the combustor (normal operation).

Compressor Control

Compressor discharge pressure and volumetric flow rate are controlled primarily by the speed of the compressor section when in the fuel cell support mode. Since the turbine, compressor and alternator are on the same shaft and the turbine section removes thermal energy from the fuel cell, the alternator load will be used as the primary control mechanism for speed control of the turbine generator. The alternator load will be controlled through the power conditioner. The signal to raise or lower the compressor flow or pressure will be sent to the PLC from the DCS. The PLC will convert this signal into a corresponding target load signal, which is sent onto the power conditioner to change the generator load. If due to process conditions, the compressor is close to the surge line and load cannot be changed to avoid the surge, a compressor emergency surge protection control valve will receive a signal to open from the PLC, which will relieve the air pressure to atmosphere. Compressor mass flow and pressure instrumentation signals are fed into the PLC to monitor the compressor surge potential.

A compressor bypass flow control valve is also provided, which connects the compressor and turbine sections. During all modes of operation, the compressor bypass flow control valve is under the supervision of the PLC control system which receives the same input signals from the compressor mass flow and pressure instrumentation mentioned above. In the standalone mode, the compressor bypass flow control valve will be fully open. In the fuel cell support mode, the compressor bypass flow control valve will be fully closed. In any mode, if the turbine generator PLC determines that the compressor is approaching surge with a pre-selected offset, then the compressor bypass flow control valve will modulate to avoid the surge so safe operation can be maintained.

Overspeed Protection

The primary mode of controlling the turbine generator speed is with the generator load. The generator load will be controlled by the PLC through the turbine generator power conditioning system. Signals to raise or lower the speed will come from the plant DCS and go to the PLC. To prevent turbine generator overspeed from fuel cell depressurization, a waste gate valve will be provided to bypasses the turbine section. The waste gate valve will fully open on detection of an overspeed condition. This valve is an open/close type of control valve.

Frequency and Voltage Control

When connected to the electric utility grid, the electric utility controls the plant AC power frequency of the plant. However, the turbine generator power conditioner will have an acceptable operating range of 59.5 to 60.5 Hz. When the frequency of the electric utility grid falls outside the operating range, the power conditioner will send a signal to the electric utility point of common coupling (typically a circuit breaker) to open and disconnect from the electric grid. Should utility disturbance cause the circuit breaker to open and then be restored to acceptable frequency limits quickly, the turbine generator power conditioner will wait for grid voltage and frequency to be within acceptable limits for 5 minutes prior to giving signal to close the breaker for reconnection to the grid. During the 5 minute wait period frequency and voltage will be adjusted to match the electric grid. When operating in island mode (i.e. disconnected from the utility), the turbine generator power conditioner will act as the master controller for frequency with the fuel cell inverters (as slaves) paralleling the turbine generator power conditioner frequency. The PLC will be preprogrammed to control the power conditioner for a 60 Hz frequency for islanded operation. Throughout the islanded operation period, the utility electric grid frequency will be monitored by the plant DCS and the PLC/power conditioner. When reconnection with the electric grid is desired, the operator will send a signal through the DCS to the PLC to synchronize back with the electric grid. The plant frequency will be adjusted by the turbine generator power conditioner to match the electric grid frequency for interconnection to the electric grid. When the frequencies are matched, the utility to plant circuit breaker will be closed.

The power conditioner will see the alternator input frequency vary up to 275 Hz with the variable speed gas turbine driver. The power conditioner will rectify the alternator input power to DC power and then invert the DC power back to usable AC power at the proper frequency and minimizing any harmonics.

When connected to the grid, the utility will determine the voltage the plant will see as the power conditioner would be considered a current source. The utility voltage will be matched with the power conditioner output voltage by the power conditioner controls and the available current would be delivered to the power plant auxiliaries with the excess going to the electric grid. If voltage falls outside the operating range of 3744 to 4576 Volts, the power conditioner will send a signal to the utility to plant circuit breaker to disconnect.

In the islanded operating mode, the power conditioner will maintain the plant voltage at a nominal 4160 Volts dependent on the auxiliary load of the plant. The acceptable operating output voltage range of the power conditioner will be 3744 to 4576 Volts. If the voltage falls outside the operating range, the power conditioner will trip the plant.

Power Factor Control

The power conditioner will have the ability to change the power factor within the operating range of 0.85 lag to lead when output is 10 percent or greater. The power conditioner will control the phase angle of the output current with respect to the line voltage. The power conditioner may have an optional power factor control capability which allows the operator, via the DCS and PLC, the capability to set a constant power factor or constant reactive power delivery.

3.B.4.c Overall Plant

In terms of hierarchy, the control system's primary function is to support the operation of the stack: - delivery of fuel and oxidant streams and the removal of waste heat.

The HEFPP is a base-load facility. For base-load power demand from the grid, a Distributed Control System (DCS) based plant control system controls the load by maintaining the required average current density for each MCFC stack in the network and by controlling the speed and power output of the turbine generator. For a particular current draw, or MCFC fuel/oxidant conversion from each stack, a particular flow of natural gas is required to maintain the per-pass utilization, at the design anode recycle ratio. Therefore, the stack current draw automatically resets the flow of natural gas fuel to the power module. To avoid oxidation of the anode itself, there must always be sufficient supply of fuel at the three-phase interface when current is being drawn from the stack.

To maintain isothermal conditions in the MCFC stacks at different current draws, the quantity of cathode feed gas is varied in response to the temperature of the cathode exhaust gas. Cathode feed gas temperature is controlled (above its minimum value) by the injection of cooling air from the compressor into the recycle blower suction.

Steam flow to the fuel processor is set on flow control. The steam supply pressure is maintained by a trim steam condenser and a steam vent, in the event of unplanned shutdowns.

Anode recycle flow is set by the steam flow to the ejector.

The steam reformer outlet temperature is controlled by adjusting the flows of heating gas from the reformer combustor and cathode recycle; a bypass arrangement. The temperature of the heating gas is controlled by trim air injection to the combustor's mixed feed stream. Air is supplied from the compressor.

Air for stack cooling, for combustor temperature control, and for power module vessel purging are all set by demand signals from within the power module. If the total air flow drops below the compressor's minimum flow, then turbine control system can increase compressor throughput by several different mechanisms.

System operating pressure is normally maintained by flow regulation at the turbine inlet; through nozzle opening, or through a throttle valve.

3.B.5. List of Major Equipment

ITEM #	MAJOR EQUIPMENT ITEM	No. UNITS	UNIT CAPACITY	MATERIAL OF CONSTRUCTION	DESIGN CHARACTERISTICS (if available)
C-200	Steam Drum	1	Separation of 6,124 kg/h of sat'd steam from BFW. Operating conditions: 896 kPa, 449 K	Carbon Steel	Elevated - natural circulation Design Pressure: 1,069 kPa, Design Temperature: 456 K
C-201	Deaerator	1	5,933 kg/h of demin. water. Operating conditions: 119 kPa, 378 K	Carbon Steel	Steam-stripped deaeration to < 7ppb O2 Design Pressure: 310 kPa & Full Vacuum Design Temperature: 408 K
C-202	Zinc Oxide Desulfurizer	1	2,257 kg/h of natural gas. Operating conditions: 720 kPa, 616 K	Low-Alloy Steel	Sulfur reduction from 4 ppmv to < 0.1 ppmv 1.50 m ID x 2.4 m T/T Design Pressure: 900 kPa Design Temperature: 680 K
E-200A	Natural Gas Pre-heater	1	Duty = 1,212,480 kJ/h	Low-Alloy Steel	Heat exchange coil in HRSG duct
E-200B	Steam Superheater	1	Duty = 1,089,840 kJ/h	Low-Alloy Steel	Heat exchange coil in HRSG duct
E-200C	Steam Boiler	1	Duty = 13,489,022 kJ/h	Carbon Steel	Natural circulation boiler in HRSG duct
E-200D	Boiler Feedwater Heater	1	Duty = 1,058,980 kJ/h	Carbon Steel	Heat exchange coil in HRSG duct
E-200E	Demineralized Water Heater	1	Duty = 1,782,940 kJ/h	Stainless Steel	Heat exchange coil in HRSG duct
K-400	Natural Gas Compressor	2	3,004 Nm^3/h gas flow 703,236 kJ/h GHP 214 kW Motor		100% units - 1 operating, 1 standby Compressor $E_{ad.}$ 70% Suction conditions: 200 kPa, 288 K Pressure Ratio 3.7
K-600	Gas Turbine/Generator Package	1	3,429 kW Generator Output		Compressor: Pressure Ratio 6.2, $E_{ad.}$ 84%, Flow 60,507 kg/h, $T_{suction}$ 288 K, GHP 3,964 kW Turbine: Pressure Ratio 5.7, $E_{ad.}$ 91.9%, Flow 68,688 kg/h, T_{inlet} 978 K, GHP 7,561 kW Generator: Eff. 98.5%
P-600	Boiler Feedwater Pump	2	6.4 m^3/h, 1,300 kPa differential head, 3.9 kW Motor	CS Casing, High-Alloy Impeller	100% units - 1 operating, 1 standby Multi-stage centrifugal

ITEM #	MAJOR EQUIPMENT ITEM	No. UNITS	UNIT CAPACITY	MATERIAL OF CONSTRUCTION	DESIGN CHARACTERISTICS (if available)
C-500	Power Module Vessel	9	3.1 m ID x 14.0 m T/T Operating conditions: 603 kPa, 550 K	Refractory-lined Carbon Steel	Horizontal cylindrical vessel, center flanged for transportation and access. Each vessel is pressurized and contains 4 (four) Power Modules (see Power-Module equipment list). Vessel is refractory lined and purged with air. Design Pressure: 720 kPa, Design Temperature: 615 K
K-500	Recycle Gas Blower	3	85,949 Nm3/h gas flow 384,120 kJ/h GHP 117 kW Motor	High-Alloy Steel	Axial Fan/Blower. Differential head 6.2 kPa, $E_{ad.,}$ 75% Suction conditions: 596 kPa, 864 K

ITEM #	MAJOR EQUIPMENT ITEM	No. UNITS	UNIT CAPACITY	MATERIAL OF CONSTRUCTION	DESIGN CHARACTERISTICS (if available)
E-501	Reformer Feed/Effluent Exchanger	36	Duty = 160,564 kJ/h	High-Alloy Steel	Operating differential pressure: < 10 kPa (hot side to cold side, inside to outside) Design Pressure: 100 kPa, Design Temperature: 1070 K
K-501	Anode Recycle Gas Ejector	36	Steam: 164.6 kg/h (872 kPa, 536 K) Anode recycle: 493.7 kg/h (604 kPa, 978 K) Pressure ratio = 1.01 Weight ratio = 3.0	High-Alloy Steel	Operating differential pressure: 280 kPa (motive steam section) Design Pressure: 500 kPa, Design Temperature: 980 K
P-501	Power Conversion System - Inverter	9	2,180 amps, 800-900V DC, 1968 kW input		4160 VAC, 3 phase, 60 Hz output - 1918 kW Efficiency 97.5%
R-501A	Pre-reformer	36	721 kg/h feed gas 24 % CH_4 conversion	Stainless Steel	Adiabatic catalytic reactor - cylindrical packed bed
R-501B	Reformer	36	721 kg/h feed gas 73.6 % CH_4 conversion Duty = 1,018,806 kJ/h	Stainless Steel	Horizontally-stacked, plate-type catalytic reactor Design Temperature:
R-501C	MCFC Stack	36	492 kW DC output		Molten-carbonate Fuel Cell 758 mV, 200 mA/cm^2 300 plates, 10,900 cm^2/plate
R-501D	Reformer Combustor	36	4,096 kg/h feed gas 1,072 K exit temperature	High-Alloy Steel	Catalytic Combustor - combustion of residual H2, CO, and CH4 in anode exhaust gas Design Temperature:
	Stepup Transformer	1	25MVA OFA 4160 V input 138KV output	Carbon Steel	Depends on utility requirements

3.C Economic Projections

3.C.1. Description of Estimate

The three most common techniques used for plant cost estimates are: - curve estimates, factored estimates, and definitive estimates.

A curve estimate relies on a historical relationship between plant capacity and cost for a particular technology. There is no historical database available yet for commercial MCFC power plants. Therefore, a curve-estimated cost is not applicable.

A factored cost estimate relies on empirical cost data collected over time from actual projects. Cost relationships between different system costs (major equipment, bulk materials, direct labor, indirect costs, etc.) are characterized from analysis of the historical data. Factors are assigned to represent the relationship. Once a cost system, say the equipment costs, is well known, the remaining plant costs can be obtained by applying these factors to the known cost items.

Again a historical database, from which factors can be derived, is not available for commercial MCFC power plants.

A definitive estimate requires a significant amount of detailed engineering to be performed (15-25%), so that material takeoffs of bulk material quantities can be used to develop accurate costs. A definitive estimate includes known site location, firm design basis, firm equipment quotations, knowledge of local construction labor markets, and a detailed construction plan.

Unfortunately, this study does not provide sufficient time or budget to develop a definitive estimate. In addition, as mentioned above, there is no historical database available to perform a curve or factored estimate. Therefore, in this case, capital costs were developed from vendor quotations and in-house equipment estimates, and installation/construction costs were developed using costs developed for the 450 kW MCFC PDI[3] unit and applying best engineering judgement.

MC-Power and Rolls-Royce Allison provided costs for the MCFC stacks and the gas turbine, respectively.

The plant construction plan is to maximize shop assembly of equipment, piping and instrumentation as packages or modules, so as to minimize construction time in the field. Module sizes are constrained by permissible shipping dimensions and weights.

Per the design basis, the capital cost estimate is based on mature technologies and integration techniques, not first-of-a-kind systems. Therefore, the assumption is that initial R&D and engineering expenditures have already been recouped by equipment vendors, and that sales price is based on competition in a mature-technology market.

[3] Process Design Improvement program – MC-Power/DOE Contract DE-FC21-95MC30133

3.C.2. Sources of Cost Data

Capital cost data for major equipment items were provided from vendor quotes. The fuel processor system costs were provided by IHI. The MCFC stack costs were provided by M-C Power. The gas-turbine generator costs were provided by Rolls-Royce Allison. The inverter costs were provided by Trace Technologies. The recycle blower costs were provided by Robinson Industries, Inc. The HRSG unit costs were provided by the G.C. Broach Company. Other costs were estimated from previous recent projects (with similar equipment) and the 1998 Richardson Process Plant Construction Estimating Standards.

3.C.3. Estimate of Capital and Operating Costs

<u>Capital Costs</u>

The capital cost estimate is based on the costs for new equipment, such as the fuel cell stacks and the plate reformers, being projected to the cost for he final stages of its evolutionary development, from both a technical standpoint and from a production/assembly standpoint. In addition, it is assumed that the HEFPP has been demonstrated to be commercially competitive (economically and environmentally) to the extent that a significant number of 20 MW units are installed each year.

Equipment vendors provided capital costs for equipment in response to preliminary equipment specification inquiries. The major equipment cost list appears in Table 12. Equipment quotes for the gas turbine generator, HRSG unit and solid-state inverters, etc. were included as received, but modified to include a 10% cost reduction for volume production, on the assumption that twenty, 20 MW HEFPP plants would be installed domestically, annually. Equipment costs for technologies continuing to undergo evolutionary development, such as the M-C Power MCFC and IHI Fuel Processor, were assumed to follow the standard cost decline curve from "high cost" for initial production, decaying to a "low-cost" plateau for future mass production. MCFC stack and fuel processor mass-production capital costs are projected to be 300 $/kW and 145 $/kW, respectively.

Sales tax on equipment purchases and transportation costs for equipment from the module assembly yard to site are assumed to be 6% and 5% of the equipment capital costs, respectively.

Bulk materials (piping, electrical, instrumentation, insulation, etc.) and labor (for equipment and bulk materials installation), subcontracts, and field indirect costs are accounted for under "Installation Costs". Installation costs for the HEFPP were estimated from detailed module fabrication/assembly costs developed for a single 450 kW module, as part of the PDI program and on typical larger conventional power plant installation costs.

Since it is intended to compare the costs and COE for the HEFPP to those for conventional, commercially-proven technologies, such as combined-cycle gas turbine power generation plants, a process equipment contingency has been applied to those equipment in the HEFPP which are in the development cycle, and whose costs were projected to mature-equipment status – it being quite possible that unforeseen factors will increase the actual mature-equipment costs.

In addition, 15% of the cost for the process plant and general plant facilities has been applied to the total capital requirement for the HEFPP (and the conventional power generation plants) as a project contingency, to address the likelihood of other project-related cost overruns.

The sum of the major equipment installed costs is the Process Plant Cost (PPC).

General plant facilities accounts for miscellaneous materials, equipment and services needed to support commercial operation of the plant, e.g. fire protection systems, in-plant roads, boundary fences, lighting, etc. The cost of these items is estimated to be 5% of PPC for the HEFPP and the gas turbine combined cycle option.

Home office engineering fees and service costs are estimated to be 7.5% of PPC with the high degree of plant modularization in both the HEFPP and the combined cycle plants.

Startup costs are assumed to consist of one month of operating labor, one month of maintenance materials, one month of consumables, one week of natural gas fuel, and one half percent of PPC for both types of plants.

Spare parts were assumed to be ½ percent of the process plant cost for both HEFPP and combined cycle plants.

Working capital is assumed to consist of three months of operating labor and two months of consumables (excluding natural gas) with a twenty-five percent contingency. Three months of maintenance materials are also included for both plants.

The total capital requirements for the HEFPP are shown in Table 13.

Operating Cost

Operating costs for the HEFPP are based on a 92% annual capacity factor and fifty weeks operation per year.

The capacity factor is an estimate, based on similar plant histories, of the percentage of name-plate capacity that a plant will actually achieve during operation. This figure is often less than 100%, due to the plant experiencing unanticipated reductions in power output, and/or unplanned shutdowns.

Two weeks per year is typical of the time period required to do annual plant maintenance.

For the present analysis, the cost of natural gas is fixed at $3.00 MMBtu (HHV).

The HEFPP plant organization chart is shown in Table 11. Operators will work in 12 hour shifts. O&M supervisor and water treatment specialist will fill in on vacation/sick leave of operators. The operations and maintenance would be similar to those expected for a combined cycle power plant of similar size on a single power plant site. The combined cycle organization was based on September, 1994 Power Magazine article "Operating and Maintaining IPP Cogen Facilities (pages 13-32).

Maintenance material costs are assumed to be 1½% of PPC and are primarily consumables. This is a historically based value, and is typical for plants requiring light service demands.

Insurance and local taxes are assumed to be 2% of PPC. In less populated areas, local property taxes are between 1-2% of the direct-capital investment. Annual insurance rates typically amount to 1% of the direct-capital investment.

Catalysts and chemicals cost include the cost of boiler water treatment chemicals and reforming catalyst replacement. Since the reforming catalyst operates under mild conditions for steam reforming catalysts, its operating life is anticipated to be approximately ten years.

The plant annual operating costs for the HEFPP are shown in Table 14.

COE Analysis

The cost of electricity (COE) is determined by NPV analysis. The COE is adjusted until the sum of the present-value cash flows, at a 15% discount rate, over the life of the plant is equal to zero.

The following basis (in addition to items mentioned above) was used for the COE analysis:

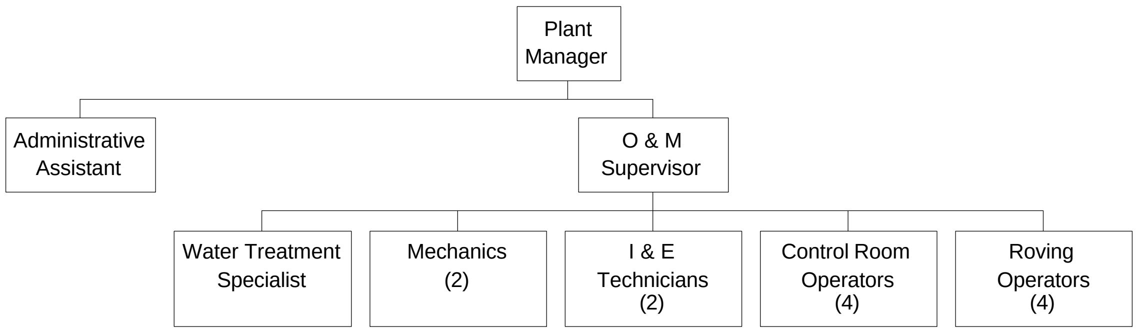
- Plant design lifetime — 25 yrs
- Capital charge rate — 15%
- Inflation allowance — none – constant dollars
- Additional capital expenditure — MCFC stack replacement every 5 yrs. Stack salvage value is assumed to be 33% of the stack equipment cost
- Depreciation — Double Declining Balance for 10 yrs, straight line remaining life
- State & Federal Taxes — 43%

Plant revenues are based on power exports for SOR and EOR assuming straight-line decline in stack performance.

The total project capital requirement is assumed to be expended over a two-year period, with one-third of the expenditure occurring in the first year. The first year has permitting and engineering, while the second year has startup and initial operation.

Project cash flows as part of the economic evaluation are shown in Table 15.

TABLE 27
HEFPP
Plant Organization Chart



Salaries (1998 Basis)

Position	Quantity	Unit Annual Salary ($)	Total Annual Salary ($)
Plant Manager	1	80,000	80,000
O & M Supervisor	1	65,000	65,000
Administrative Assistant	1	25,000	25,000
Water Treatment Specialist	1	30,000	30,000
Mechanics	2	30,000	60,000
I/E Technicians	2	40,000	80,000
Control Room Operator	4	40,000	160,000
Roving Operator	4	35,000	140,000
TOTAL	16		640,000

Table 28
HEFPP
Major Equipment Cost List

ITEM #	MAJOR EQUIPMENT ITEM	EQUIPMENT COST/UNIT	SALES TAX/ UNIT	FREIGHT COST/UNIT	INSTALLATION COST/UNIT	TOTAL COST/UNIT	QUANTITY	TOTAL COST
	HRSG unit/deaerator	$202,140	$12,128	$10,107	$60,642	$285,017	1	$285,017
C-200	Steam Drum							
E-200A	E-200A Natural Gas Pre-heater							
E-200B	Steam Superheater							
E-200C	Boiler							
E-200D	Boiler Feedwater Heater							
E-200E	Demineralized Water Heater							
C-201	Deaerator							
C-202	**Zinc Oxide Desulfurizer**	$11,179	$671	$559	$27,948	$40,356	1	$40,356
K-400	**Natural Gas Compressor**	$50,000	$3,000	$2,500	$100,000	$155,500	2	$311,000
C-500	**Power Module Vessel**	$84,667	$5,080	$4,233	$127,001	$220,981	9	$1,988,828
K-500	**Recycle Blower**	$108,000	$6,480	$5,400	$162,000	$281,880	3	$845,640
K-501	**Anode Recycle Gas Ejector**	$3,600	$216	$180	$360	$4,356	36	$156,816
P-501	**Power Conversion System - Inverter**	$180,000	$10,800	$9,000	$27,000	$226,800	9	$2,041,200
	Fuel Processor (w/catalyst)	$72,500	$4,350	$3,625	$29,000	$109,475	36	$3,941,100
E-501	Reformer Feed/Effluent Exchanger							
R-501A	Pre-reformer							
R-501B	Reformer							
R-501D	Reformer Combustor							
R-501C	**MCFC Stack**	$150,000	$9,000	$7,500	$45,000	$211,500	36	$7,614,000
K-600	**Gas Turbine-Generator Package**	$724,000	$43,440	$36,200	$99,188	$905,000	1	$905,000
P-600	**Boiler Feedwater Pump**	$2,500	$150	$125	$7,500	$10,275	2	$20,550
	Plant Control System	$650,000	$39,000	$32,500	$65,000	$786,500	1	$786,500
	Electrical Switchgear	$187,000	$11,220	$9,350	$37,400	$244,970	1	$244,970
	Stepup Transformer	$187,500	$11,250	$9,375	$37,500	$245,625	1	$245,625
								$19,426,602

Table 29
Electric Power Generation Cost

AREA No.	PLANT SECTION DESCRIPTION	PROCESS CONT., %	COST, K$ w/o CONT.
	HRSG Unit/Deaerator		285
	Zinc Oxide Desulfurizer		40
	Natural Gas Compressor		311
	Power Module Vessel	5	1,989
	Recycle Blower	10	846
	Anode Recycle Gas Ejector		157
	Inverter	10	2,041
	Fuel Processor	10	3,941
	MCFC Stack	10	7,614
	Gas Turbine/Generator Package		905
	BFW Pump		21
	Plant Control System		787
	Electrical Switchgear		245
	Stepup Transformer		246
	Subtotal, Process Plant Cost		19,427
General Plant Facilities			971
Engineering Fees			1,457
Process Contingency (Using conntingencies listed above)			1,544
Project Contingency, 15 % Proc. Plt. & Gen. Plt. Fac.			3,060
	Total Plant Cost		26,458
Prepaid Royalties			
Initial Catalyst and Chemical Inventory			15
Startup Costs			334
Spare Parts			97
Working Capital			301
Land, 1 Acres			25
	Total Capital Requirement (TCR)		**27,230**
		$/kW	**1,362**

Table 30
Annual Operating Costs

COST ITEM		QUANTITY		UNIT $ PRICE		ANNUAL COST, K$
~~Natural Gas~~	Fuel Type	2609.3	MMBtu/D	$ 3.00	/MMBtu	$ 2,527.46
Consumable Materials						
Demineralized Water		37.67	Mgal/D	$ 3.00	/Unit	$ 36.49
Catalysts & Chemicals			Unit/D		/Unit	$ 100.00
Fuel Cell Stack Replacement			Unit/D		/Unit	
			Unit/D		/Unit	
Disposal Costs (If any)			Unit/D		/Unit	
Plant Labor						
Operating Labor (incl. benef.)		See Plant Organization Chart				$ 640
Supervision & Clerical						
Maintenance Costs						$ 291
Insurance & Local Taxes						$ 389
Royalties						
Other Operating Costs						
		Total Operating Costs				$ 3,983.88
By-Product Credits						
			Unit/D		/Unit	
			Unit/D		/Unit	
			Unit/D		/Unit	
			Unit/D		/Unit	
			Unit/D		/Unit	
Total By-Product Credits						
Net Operating Costs						**$ 3,983.88**

TABLE 31

COE - $/kW-h, NPV Calculation

CASE: 20 MW MCFC-Based HEFPP Facility

TOTAL PROJECT COST 27.23 $MM

End of Proj. Year	End of Opn. Year	Investment-related Cash Flows $1,000 Total Plant Cost (a)	Working Capital (b)	Total	Before Tax Operating Cash Flows $1,000 Sales Revenue (c)	Production Costs (d)	Net Opn. Cash Flows	Tax Calculations $1,000 Depreciation (DDB) (e)	Tax Allowance Earned in Previous Year	Taxable Profit in Previous Year	Tax Payable (f)	After Tax Operating Cash Flow	Cash Flows Project Net Cash Flow	NPV $1,000 Discounted at IRR of 15.00%
1		(8,819)	(152)	(8,971)									(8,971)	(8,971)
2		(17,639)	(620)	(18,259)									(18,259)	(15,877)
3	1	0	0	0	9,758	(3,984)	5,774					5,774	5,774	4,366
4	2	0	0	0	9,666	(3,984)	5,682	8,172	8,172	(2,397)	1,031	6,712	6,712	4,414
5	3	0	0	0	9,573	(3,984)	5,589	6,537	6,537	(856)	368	5,957	5,957	3,406
6	4	0	0	0	9,485	(3,984)	5,501	5,230	5,230	359	(154)	5,347	5,347	2,658
7	5	0	0	0	9,387	(3,984)	5,404	4,184	4,184	1,317	(566)	4,837	4,837	2,091
8	6	(3,600)	0	(3,600)	9,758	(3,984)	5,774	3,347	3,347	2,056	(884)	4,890	1,290	485
9	7	0	0	0	9,666	(3,984)	5,682	2,678	2,678	3,097	(1,332)	4,350	4,350	1,422
10	8	0	0	0	9,573	(3,984)	5,589	2,142	2,142	3,540	(1,522)	4,067	4,067	1,156
11	9	0	0	0	9,485	(3,984)	5,501	1,714	1,714	3,875	(1,666)	3,835	3,835	948
12	10	0	0	0	9,387	(3,984)	5,404	1,371	1,371	4,130	(1,776)	3,628	3,628	780
13	11	(3,600)	0	(3,600)	9,758	(3,984)	5,774	1,097	1,097	4,307	(1,852)	3,922	322	60
14	12	0	0	0	9,666	(3,984)	5,682	313	313	5,461	(2,348)	3,333	3,333	542
15	13	0	0	0	9,573	(3,984)	5,589	313	313	5,368	(2,308)	3,281	3,281	464
16	14	0	0	0	9,485	(3,984)	5,501	313	313	5,276	(2,269)	3,233	3,233	397
17	15	0	0	0	9,387	(3,984)	5,404	313	313	5,188	(2,231)	3,173	3,173	339
18	16	(3,600)	0	(3,600)	9,758	(3,984)	5,774	313	313	5,090	(2,189)	3,586	(14)	(1)
19	17	0	0	0	9,666	(3,984)	5,682	313	313	5,461	(2,348)	3,333	3,333	269
20	18	0	0	0	9,573	(3,984)	5,589	313	313	5,368	(2,308)	3,281	3,281	231
21	19	0	0	0	9,485	(3,984)	5,501	313	313	5,276	(2,269)	3,233	3,233	198
22	20	0	0	0	9,387	(3,984)	5,404	313	313	5,188	(2,231)	3,173	3,173	169
23	21	(3,600)	0	(3,600)	9,758	(3,984)	5,774	313	313	5,090	(2,189)	3,586	(14)	(1)
24	22	0	0	0	9,666	(3,984)	5,682	313	313	5,461	(2,348)	3,333	3,333	134
25	23	0	0	0	9,573	(3,984)	5,589	313	313	5,368	(2,308)	3,281	3,281	115
26	24	0	0	0	9,485	(3,984)	5,501	313	313	5,276	(2,269)	3,233	3,233	98
27	25	0	1,000	1,000	9,387	(3,984)	5,404	313	313	5,188	(2,231)	3,173	4,173	110
28	26													
29	27													
		(40,858)						40,858					NPV =	$0.00

(*)	Fuel Cell Stack replacement every 5 years, with credit taken for salvage @ 33% of stack cost	**Operating Days/Year**	**351**		
(a)	1998 Capital Investment of............... 27.23 $MM	**SOR Power Output, MW**	**20.1**	**@ cap fac.**	**0.92**
(b)	Recovered at end of project	**Elect Value, $/kW h**	**0.063**		
(c)	Electricity Value x Power Output (@cap fac.) x Opn. Days/year	**EOR Power Output, MW**	**19.2**		
(d)	From Operating Cost Table				
(e)	Double-declining-balance depreciation for 10 years, followed by straight-line depreciation for remaining project life. Zero salvage value				
(f)	Combined State and Federal Tax rate of 43%.				

3.C.4. Economic Analysis Results

The COE for a mature technology 20 MW MCFC-based power plant (for the above design basis and assumptions) is 6.3 cents/kW-hr. The total project capital requirement for the turnkey facility is $1362/kW.

In performing the economic analysis for the MCFC-based HEFPP, no cash-flow credits were assigned for the reduced emissions of air pollutants and greenhouse gases characteristics of this type of facility.

3.C.5. Comparison of Fuel Cell Power Plant with Competing Technology

This section compares the MCFC-based HEFPP power plant to similar sized, conventional, fossil-fuel power generation systems. The power generation system selected includes a gas turbine based combined-cycle gas turbine producing 22 MW (16 MW GT, 6 MW steam turbine) gross and 20.2 MW net. Each system is assumed to operate as a base-load unit.

The power plant performance, costs, and COE for a 15% capital charge rate, for each of these units are compared below.

1. Power Plant Efficiency

This performance criteria refers to the efficiency at which each of these power generation systems converts chemical energy in the fuel to net electric power, i.e. the quantity of power available for export to the grid once auxiliary loads have been subtracted.

Combined Cycle Gas Turbine performance figures were obtained from 1998 Gas Turbine World Handbook.

The Table below summarizes the efficiency for each plant.

Plant Efficiency

	CC-GT	HEFPP
Efficiency (LHV),%	43.3	70.1
kJ/kW-h	8,314	5,134
kcal/kW-h	1,986	1,227
Btu/kW-h	7,882	4,868
Nat. Gas, Std.* M^3/kW-h	0.242	0.149

*0°C, 101.3 kPa

Clearly, the MCFC-based HEFPP is significantly more efficient at converting chemical energy in fossil-fuel reserves to electric power.

Note: No attempt has been made to increase plant efficiency by including additional heat recovery to low-grade, closed-loop heating cycles, or refrigeration cycles.

2. Plant Emissions

Known pollutants associated with fossil-fuel power plants include sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide, unburned hydrocarbons, and particulate matter.

NO_x

To meet the prevailing emission requirements, gas turbine combined cycle plants must include either low NO_x burners and/or post-combustion NO_x reduction technology. Dry, low-NO_x burners typically achieve NO_x emissions in the range of ppmv. ABB was contacted and the GT-

35 used in the study presently has a NO_x value of 45 ppm. The 25 ppm value will not be available until 2001. The study however has assumed that the 25 ppm NO_x machine is available for purposes of the study. This is roughly equivalent to 2,500 metric tonnes of NO_x emissions over the 25-year life of the 22 MW CC-GT plant. Further reductions in NO_x emissions can be achieved by including best available control technology (BACT) such as a selective catalytic reduction unit (SCR), or catalytic control technology like $SCONO_x$™, which has recently pushed the lowest achievable emissions rate for NO_x to 2-3 ppmv. Emission of 3 ppmv NO_x over the plant life is equivalent to emitting 320 metric tonnes of NO_x. Typical performance for SCRs is in the region of 9 ppmv NO_x. By using the SCR technology, unreacted ammonia release into the atmosphere requires monitoring in the exhaust stack. Other pollutants such as NO_x, CO, and unburned hydrocarbons must also be monitored by a continuous emissions monitoring system. This system requires a significant amount of maintenance and utilizes a significant amount of calibration gases for proper operation.

NO_x production in the HEFPP is expected to be extremely low. South Coast Air Quality Management District (SCAQMD)(located in the Los Angeles area) tests for Phosphoric Acid Fuel Cell (PAFC) atmospheric emissions, measured NO_x emissions as <1 ppmv. MCFCs are expected to achieve even lower NO_x emission levels, since less combustion is needed to provide the heat for the fuel processing step. In addition, since all of the gas from the fuel processor's catalytic combustor passes through the MCFC cathode compartment, which is an excellent "NO_x scrubber"[4], the emission of NO_x from the stack should be negligible. NO_x measurements taken by IHI on their MCFC stack were undetectable on equipment with a 1 ppmv lower detectable limit.

At 1 ppmv NO_x emission, the quantity of NO_x emitted over the 25-year life of the HEFPP would be 23 metric tonnes.

It is important to emphasize that combustion turbine based power plants, where the turbine combustor continuously fires fuel to sustain the cycle, cannot yet achieve the NO_x emission performance of a MCFC-based power plant.

The Table below illustrates the estimated NO_x emissions from each plant.

NO_x Emissions

	CC-GT	HEFPP
NO_x Emission (low NO_x bnr. + SCR)	3 ppmv	<1 ppm
NO_x emitted over life of plant, MT	316	<23

SO_x

The amount of SO_x generated depends on the quantity of fuel combusted and its sulfur content. Since the MCFC-based HEFPP 1) desulfurizes its fuel feedstock, 2) has a higher natural-gas-conversion efficiency, 3) will capture desulfurization trace sulfur (<0.1 ppmv) in the pre-reforming/reforming section, and 4) does not fire the gas turbine combustor during normal

[4] A.J. Appelby, Characteristics of Fuel Cell Systems.

operation, the amount of sulfur emitted from the plant can be considered negligible, or insignificant.

The Table below illustrates the estimated SO_x emissions from each plant.

SO_x Emissions

	CC-GT	**HEFPP**
SO_x emitted over life of plant, MT	12.2	<0.2

CO_2

There is increasing support being given to the viewpoint that the continued emission of so-called greenhouse gases is causing changes to the global climate. Human-based activities leading to the emission of carbon dioxide, methane, chlor-fluorocarbons, and other gases are believed to be the main contributors to the climate change.[5] At the Kyoto conference, Annex 1 countries agreed to an average reduction of 5.2% in greenhouse gas emissions by the period 2008-2012.

By virtue of its superior fuel conversion efficiency, the MCFC-based HEFPP has one of the lowest CO_2 emissions rating of any commercial, or near-commercial, fossil-fuelled power plants.

The Table below illustrates the estimated CO_2 emissions from each plant.

CO_2 Emissions

	CC-GT	HEFPP
CO_2 emitted over life of plant, MT	$2.1x10^6$	$1.1x10^6$

As summarized in the three tables above, the MCFC-based HEFPP emits significantly less air pollutants and greenhouse gases than the competing fossil-fuel power generation systems.

Power Plant Economic Analysis

1. Cost of Electricity

The cost of producing electric power for each system is summarized below. The basis for comparison is:-natural gas price $3.00/MMBtu (HHV), capital charge rate 15%, capacity factor 92%, and plant life 25-years.

The COE comparison is summarized below, while detailed capital and operating costs and the NPV analyses for the gas turbine combined cycle facilities are presented in Tables 32, 33, and 34.

The costs for the gas turbine combined cycle were obtained from recent power plant publications. Costs for SCR NOx control systems, plant control systems, and continuous

[5] K. Thambimuthu and P. Freuund IEA Greenhouse Gas R&D Programme.

emissions monitoring systems were added to the gas turbine simple cycle and combined cycle projects. Project line-item costs below the PPC (engineering fees, project contingency, working capital, spare parts, maintenance, local taxes and insurance, etc.) were applied at the same rates as used for the HEFPP capital and operating cost estimates. No process equipment contingencies were applied to the gas turbine or steam turbine cycles – although a 10% contingency was applied to the estimated cost for the SCR. Based on discussions with ABB, the entire plant would have a major overhaul covering the gas turbine generator, steam turbine generator, HRSG, cooling tower, condenser and other balance of plant equipment every five years. ABB recommended that the five year overhaul costs should be based on $2.00/MWh of operation. This major overhaul would last four weeks and would impact the sales revenues for the overhaul years. It should be noted that the gas turbine will have to come off line for ten hours for water washing the compressor section every two months. Power plant output also degrades approximately one half percent per year between plant major overhauls due to gas turbine and steam turbine performance degradation. Catalyst and chemical costs will be significantly higher for the combined cycle plant due to plant lube oils, cooling tower water treatment chemicals, CEM calibration gases, gas turbine washing fluids and SCR ammonia.

COE Comparison

		CC-GT	**HEFPP****
Total Plant Investment, $MM		23.2	27.2
	$/kW	1161	1362
Annual Operating Costs, $MM		6.13	3.98
(Based on $3.00/MMBtu gas)			
COE* for $1.50/MMBtu gas, ¢/kW-h		**5.6**	**5.4**
COE*, for $3.00/MMBtu gas,¢/kW-h		**7.1**	**6.3**
COE*, for $5.00/MMBtu gas, ¢kW-h		**9.1**	**7.4**

* -after depreciation and State and Federal taxes.
** -no financial credits have been taken for the environmental benefits of the MCFC-based HEFPP.

TABLE 32
Combined Cycle Gas Turbine
Power Plant Capital Cost

AREA No.	PLANT SECTION DESCRIPTION	PROCESS CONT., %	COST, K$ w/o CONT.
	Gas turbine generator		6,882
	HRSG		
	Steam turbine generator set		4,440
	Condenser		
	Cooling Tower		
	Transformer & Switchgear		
	Nat Gas Compressor		600
	Balance of Plant		3,885
	BACT SCR System (3ppmv NOx)	10	600
	Continuous Emissions Monitoring System		237
	Plant Control System (DCS)		787

Subtotal, Process Plant Cost	17,431
General Plant Facilities	872
Engineering Fees	1,307
Process Contingency (Using conntingencies listed above)	60
Project Contingency, 15 % Proc. Plt. & Gen. Plt. Fac.	2,745
Total Plant Cost	22,415
Prepaid Royalties	
Initial Catalyst and Chemical Inventory	20
Startup Costs	362
Spare Parts	87
Working Capital	315
Land, 1 Acres	25
Total Capital Requirement (TCR)	**23,225**
$/kW	**1,161**

TABLE 33
Combined Cycle Gas Turbine
Annual Operating Costs

COST ITEM		QUANTITY		UNIT $ PRICE		ANNUAL COST, K$	
~~Natural Gas~~	Fuel Type	4,789	MMBtu/D	$ 3.00	/MMBtu	$	4,639
Consumable Materials							
Demineralized Water		3	Mgal/D	$ 3.00	/Unit	$	3
Catalysts & Chemicals			Unit/D		/Unit	$	238
Turbine Blade Replacement			Unit/D		/Unit		
			Unit/D		/Unit		
Disposal Costs (If any)			Unit/D		/Unit		
Plant Labor							
Operating Labor (incl. benef.)		Operating Staff Number and Costs Similar to HEFPP				$	640
Supervision & Clerical							
Maintenance Costs						$	261
Insurance & Local Taxes						$	349
Royalties							
Other Operating Costs							
		Total Operating Costs				$	6,129
By-Product Credits							
			Unit/D		/Unit		
			Unit/D		/Unit		
			Unit/D		/Unit		
			Unit/D		/Unit		
			Unit/D		/Unit		
Total By-Product Credits							
Net Operating Costs						**$**	**6,129**

TABLE 34

COE - $/kWh, NPV Calculation

CASE: 22 MW CC-GT Plant

TOTAL PROJECT COST 23.23 $MM

End of Proj. Year	End of Opn. Year	Investment-related Cash Flows $1,000 Total Plant Cost (a)*	Working Capital (b)	Total	Before Tax Operating Cash Flows $1,000 Sales Revenue (c)	Production Costs (d)	Net Opn. Cash Flows	Tax Calculations $1,000 Depreciation (DDB) (e)	Tax Allowance Earned in Previous Year	Taxable Profit in Previous Year	Tax Payable (f)	After Tax Operating Cash Flow	Cash Flows Project Net Cash Flow	NPV $1,000 Discounted at IRR of 15.00%
1		(7,472)	(161)	(7,632)									(7,632)	(7,632)
2		(14,944)	(649)	(15,593)									(15,593)	(13,559)
3	1	0	0	0	11,098	(6,129)	4,969					4,969	4,969	3,757
4	2	0	0	0	11,043	(6,129)	4,914	5,121	5,121	(152)	65	4,979	4,979	3,274
5	3	0	0	0	10,988	(6,129)	4,858	4,097	4,097	817	(351)	4,507	4,507	2,577
6	4	0	0	0	10,932	(6,129)	4,803	3,278	3,278	1,581	(680)	4,123	4,123	2,050
7	5	0	0	0	10,877	(6,129)	4,747	2,622	2,622	2,181	(938)	3,810	3,810	1,647
8	6	(798)	0	(798)	10,655	(6,129)	4,525	2,098	2,098	2,650	(1,139)	3,386	2,588	973
9	7	0	0	0	11,043	(6,129)	4,914	1,678	1,678	2,847	(1,224)	3,689	3,689	1,206
10	8	0	0	0	10,988	(6,129)	4,858	1,342	1,342	3,571	(1,536)	3,323	3,323	944
11	9	0	0	0	10,932	(6,129)	4,803	1,074	1,074	3,784	(1,627)	3,176	3,176	785
12	10	0	0	0	10,877	(6,129)	4,747	859	859	3,944	(1,696)	3,052	3,052	656
13	11	(798)	0	(798)	10,655	(6,129)	4,525	687	687	4,060	(1,746)	2,780	1,982	370
14	12	0	0	0	11,043	(6,129)	4,914	196	196	4,329	(1,861)	3,052	3,052	496
15	13	0	0	0	10,988	(6,129)	4,858	196	196	4,717	(2,028)	2,830	2,830	400
16	14	0	0	0	10,932	(6,129)	4,803	196	196	4,662	(2,005)	2,798	2,798	344
17	15	0	0	0	10,877	(6,129)	4,747	196	196	4,606	(1,981)	2,767	2,767	296
18	16	(798)	0	(798)	10,655	(6,129)	4,525	196	196	4,551	(1,957)	2,568	1,771	165
19	17	0	0	0	11,043	(6,129)	4,914	196	196	4,329	(1,861)	3,052	3,052	247
20	18	0	0	0	10,988	(6,129)	4,858	196	196	4,717	(2,028)	2,830	2,830	199
21	19	0	0	0	10,932	(6,129)	4,803	196	196	4,662	(2,005)	2,798	2,798	171
22	20	0	0	0	10,877	(6,129)	4,747	196	196	4,606	(1,981)	2,767	2,767	147
23	21	(798)	0	(798)	10,655	(6,129)	4,525	196	196	4,551	(1,957)	2,568	1,771	82
24	22	0	0	0	11,043	(6,129)	4,914	196	196	4,329	(1,861)	3,052	3,052	123
25	23	0	0	0	10,988	(6,129)	4,858	196	196	4,717	(2,028)	2,830	2,830	99
26	24	0	0	0	10,932	(6,129)	4,803	196	196	4,662	(2,005)	2,798	2,798	85
27	25	0	1,000	1,000	10,877	(6,129)	4,747	196	196	4,606	(1,981)	2,767	3,767	99
28	26													
29	27													
		(25,606)						25,606					NPV =	$0.00

Operating Days/Year	**351**
SOR Power Output, MW	**20.2 @ cap fac. 0.92**
Elect Value, $/kWh	**0.071**
EOR Power Output, MW	**19.7**

(*) Gas Turbine, HRSG & Steam Turbine, and BOP Major Overhaul every 5 years with outside contractors.

(a) 1998 Capital Investment of.............. 23.23 $MM

(b) Recovered at end of project

(c) Elect Value x Power Output (@cap fac.) x Opn. Days/year (Power Degrades @1%/yr between rebuilds)

(d) From Operating Cost Table

(e) Double-declining-balance depreciation for 10 years, followed by straight line depreciation for remaining project life. Zero salvage value

(f) Combined State and Federal Tax rate of 43%.

4. CONCLUSION

This study has confirmed that Pressurized Molten Carbonate Fuel Cell technology can be combined with gas turbine generator technology to produce a power plant with 70% low heating value efficiency when utilizing natural gas as a fuel. The study also confirmed that the HEFPP concept produced significantly lower 6.3 cents/kWh cost of electricity when compared to a similar sized gas turbine combined cycle plant with a 7.1 cents/kWh cost of electricity based on a natural gas fuel cost of $3.00/MMBtu. The HEFPP cost of electricity sensitivity to fuel cost was investigated with fuels ranging from $1.50 to $5.00 per MMBtu. In all cases the HEFPP concept was considerably cheaper in cost of electricity than a gas turbine combined cycle plant of similar size.

This study has assumed that investments in the HEFPP components will be made to drive the component costs down and to eliminate the technical issues. Specific components requiring further investment and development time include fuel cell stacks, gas turbine generator, recycle blower, power module vessels, inverter, reformer, and plant control philosophy.

Most of the development items on the molten carbonate fuel cell are already being addressed under M-C Power's Process Design Improvement program funded by DOE.

With the HEFPP concept, the fuel cell will have design and development issues related to operation at 610 kPa. The gas compositions and flow rate will affect pressure drop and cell performance. The higher pressure may result in higher output per stack because the internal manifolds will shrink and the active area increase. Bench, small area, and full area stack performance testing will be required to confirm predicted current densities and voltages with actual gas compositions at the 610 kPa pressure. Endurance testing of fuel cell stacks will also be required to determine if pressure has an effect on stack components. Series connections for four cells will also have to be designed and tested.

Many of the turbine generator components are of new design or must be scaled up or down to meet the specific application. These components will require engineering, fabrication development, and prototype testing prior to use in the power plant. Specific examples include the active magnetic bearings, direct drive alternator, turbine generator controls, and the power conditioner.

The recycle blower temperature problems are being worked through at the Miramar plant, but the shaft sealing solutions at a pressure of 606 kPa must be developed and tested. The limited number of manufacturers with experience at this operating pressure also presents a problem.

The power module vessel will require some design work to conquer the design constraints imposed both internally and externally. In this case, Bechtel National, a vessel fabricator, and the module fabricator will have to work closely to develop the design. Input will be required from M-C Power and IHI for the fuel cell and reformer installation/operation/maintenance issues, respectively.

The inverter design and development issues appear much more straightforward than the other components mentioned above. The most important inverter design challenges include the efficiency improvement, technology selection, product repackaging, and performance testing issues. Most of the issues can be resolved by a contractual relationship with an inverter manufacturer. Once the product is developed and tested successfully, the inverter manufacturer may have a significant competitive advantage in technology and product introduction over rivals who have not developed or tested products.

The reformer design will require some development work to accommodate the higher operating pressure of 610 kPa. At higher pressures, the specific volume of the gases is smaller which will reduce the pipe diameter and plate spacing. The higher pressure will however require thicker pipe materials to be used. Some development work and testing will also be required to meet the catalyst life goal of 80,000 hours or ten years.

The overall plant control concept also will require refinement. Integration of the turbine generator and multiple fuel cell inverters will require design work. Strategies for response to electrical system transients such as loss of electric grid, ground faults in a single phase or neutral must be developed. Modeling work will be required to determine HEFPP capabilities for load following, load shedding, and plant turndown.

The plant control system will also have to integrate the individual component control systems for the gas turbine generator and inverter with the other equipment in the plant.

Finally, the technical challenges mentioned above are not insurmountable and can be overcome with time and targeted funding. Clearly, much of the technology exists today and has been proven on a smaller scale by M-C Power at Miramar and in the future will be proven by M-C Power's 450 kW class molten carbonate fuel cell hybrid power plant using a micro gas turbine generator. The HEFPP concept is feasible and predicted performance levels can be met. This study has presented the plans and approaches required to solve the performance, life and cost issues by 2010 or sooner. The proposed HEFPP concept will produce a low cost of energy and environmentally friendly plant with significantly lower emissions than the gas turbine generator combined cycle plants of today.